THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Master of Science (Environmental Science)
DEGREE

Environmental Science	Environmental Science
FIELD	**DEPARTMENT**

TITLE: Watershed Management for Controlling Water Quality of Phetchaburi River, Phetchaburi Province, Thailand

NAME: Mr. Soulivanh Voravong

THIS THESIS HAS BEEN ACCEPTED BY

______________________________ **THESIS ADVISOR**
(Professor Kasem Chunkao, Ph.D.)

______________________________ **THESIS CO-ADVISOR**
(Assistant Professor Surat Bualert, Ph.D.)

______________________________ **DEPARTMENT HEAD**
(Assistant Professor Surat Bualert, Ph.D.)

APPROVED BY THE GRADUATE SCHOOL ON ______________________________

______________________________ **DEAN**
(Associate Professor Gunjana Theeragool, D.Agr.)

THESIS

WATERSHED MANAGEMENT FOR CONTROLLING WATER QUALITY OF PHETCHABURI RIVER, PHETCHABURI PROVINCE, THAILAND

SOULIVANH VORAVONG

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Science (Environmental Science)
Graduate School, Kasetsart University
2014

Soulivan Voravong 2014: Watershed Management for Controlling Water Quality of Phetchaburi River, Phetchaburi Province, Thailand. Master of Science (Environmental Science), Major Field: Environmental Science, Department of Environmental Science. Thesis Advisor: Professor Kasem Chunkao, Ph.D. 146 pages.

Water quality degradation in Phetchaburi river will still be present in the years to come since water pollutions from municipal wastewaters, industrial wastewaters, and agricultural practices are not visible to be handled effectively. The research was aimed to find means how to handle water at Phetchaburi diversion dam for coping with stream pollution in Phetchaburi river through irrigation watershed management. There eight sampling points for collecting water samples since the year of 2002 to 2013 for analysing water quality in relation to release water flow in consecutive velocity of 22.4, 100, and 377m^3/s in order to obtain the better diluted stream water. Accordance with the same trends of water quality indicators, this study was taken in 10 water quality indicators included water temperature, pH, TDS, BOD, DO, EC, NO_3, HN_3, TCB and FCB as the representatives for determining the role of flow velocity in dilution capability. The results found that water temperature changed a little in municipal area, pH increased when water flow increase, EC and TDS decreased when water flow increased, NO3 increased if water flow increased and HN3 not detected when water flow increased, TCB and FCB increased when water flow increased particularly water flow throughout density communities, the BOD were gradually decreased from Phetchaburi diversion dam all the way to agricultural zone and jumping up during passing the city zone, and still jumping up in estuarine zone. Whenever the BOD decreases, the DO values were also decreased because of bacterial organic digestion process occurring while it flows except very high flow velocity. The flow velocity less 30 m^3/s is recommended to release from Phetchaburi diversion dam for eliminating stream pollution by dilution process.

__________________ Student's signature

__________________ Thesis Advisor's signature

___ / ___ / ___

ACKNOWLEDGEMENTS

This thesis would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study. First and foremost, I would like to express my sincere gratitude to Professor Kasem Chunkao, Ph.D, Chair of my Guidance Committee, for the continuous guidance and insightful comments and brilliant suggestions. His patience, motivation, and immense knowledge helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my Masters study program.

My profound appreciation goes to Assistant Professor Surat Bualert, Ph.d, member of my Guidance committee, for his encouragement, insightful comments and brilliant questions which helped my research in balanced shape as well as all of his helps during my studies and stay in Thailand.

I would like to thanks all the professors from Department of environmental science for sharing and enhancing to my valuable knowledge during my studies and stay in Kasetsart University. My sincere thanks go to Dr. Satreethai Poommai, Mr. Watcharapong Wararam, Mr. Chatri Nimpee and Dr. Thanit Pattamatoon, for all their support and guidance during data analysis and gathering in the study site and thanks for international studies center. I would like to special thanks to SEARCA and LERD provided and supported the finance for my during study and stay in Thailand, without their support and encouragement my Master degree study would not have been possible, and I am grateful to Graduate School staffs for their support throughout my stay at KU.

Lastly, I would like to thank my family and friends particularly my wife for supporting and encouraging me to pursue this degree. Without their support and encouragement of this would have been possible.

Soulivanh Voravong

May 2014

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF ABBREVIATIONS

BOD	=	Biochemical oxygen demand
DO	=	Dissolved oxygen
RID	=	Royal Irrigation Department
DOWR	=	Department of Water Resources
EC	=	Electrical conductivity
FCB	=	Fecal coliform bacteria
Ha	=	Hectare
HAII	=	Hydro and Agro information institute
LDD	=	Land Development Department
LERD	=	King's Royally initiated Laem Phak Bia environmental research and development project
L	=	Litter
MPN	=	Most probable number
MCM	=	Million Cubic Meter
MD	=	Methodology Department
mg	=	Milligram
ml	=	Millilitre
NO_3-N	=	Nitrate-nitrogen
NH_3-N	=	Ammonia-nitrogen
PCD	=	Pollution control Department
SW1	=	Sample water point 1
TCB	=	Total coliform bacteria
TDS	=	Total dissolved solid
U.S.EPA	=	United stated environment protection agency
WSC	=	Watershed classification

WATERSHED MANAGEMENT FOR CONTROLLING WATER QUALITY OF PHETCHABURI RIVER, PHETCHABURI PROVINCE, THAILAND

INTRODUCTION

King Bhumibal's slogan on "water is life" and few years later being used by United Nations (UN) has been taken in basic principles for managing water resources in the whole country of Thailand. The word of "water is life" is very necessary in Thailand which is the land of food producing for domestic consumption and exporting all parts of the world. Generally, the said food products are obtained from crop cultivation and livestock farming in which the rain and irrigated water are really needed to grow rice, fruits and vegetables; and also to feed livestock and aquaculture farming. In addition, water is still very necessary for human life and their activity as the same as cultural servicing from giving birth to death. Naturally, the country receives annual rain water about 800,000 MCM which is lost by evaporation and transpiration into the sky 600,000 MCM (75 %) and flowing in the streams 200,000 (25 %); only 20 % of stream flow (40,000 MCM) can be stored in 15 big dams plus more than 6,000 small dams. It has been horrible since the year of 1970 on about wet flow more 95 % and dry flow less 5 % of total annual flow which indicated too much water in wet period and water storage in dry period that would be the big problem of agricultural in the whole country. At the same time, the stream pollution has be expanded from dense population in the cities and industrial factories due to lack of stream flow in dry season for diluting on high wastewater concentration.

Actually, the grassroots of the stated problem has been up to the destruction of forest cover in head watershed areas causing high concentration on 4-month period flow regime in wet season while very low flow on 8-month period found in dry season. In other words, the dense forest cover of watershed is presumably generated stream flow all year round; it might be a little high peak in wet season and lower flow in dry season, but it might be clearly distorted in abnormal year that making the trend of flow different from the long-period stream flow recording. Even though the dense forest watershed can produce all-year water quantity but water quality may occur in case of various point sources to release much more pollutants to become stream pollution. However, if watershed was well managed, the water quantity and quality as well as flow regime would be on the target.

Headwater of Phetchaburi river watershed is exactly covered with dense forest which belongs to Kaeng Krachan National Park in Phetchaburi province that producing high amount of water quantity and good water quality along with perennially flow regime from the Kaeng Krachan storage dam down to the Phetchaburi diversion dam. After that, the water quality was gradually decreased due to the addition of community organic wastes and agricultural chemical pollutants on both riverbanks of Phetchaburi river. Unfortunately, not desirable water quality found on the location of the dense populated villages and big cities, especially Phetchaburi and Thayang municipals, in dry period rather than wet period. Also, the irrigation draining into paddy fields for growing rice without considering to maintain the optimum water quantity in Phetchaburi river would be another reason why stream pollution occurring at the point sources of community and dense population locations. Hypothetically, well-managed planning on Phetchaburi river watershed would be served needs for water quality control in order to maintain the sustainable abundance of environment in Phetchaburi river ecosystems.

On the other hand, Phetchaburi river basin is mostly comprised of double-crop paddy field for rice growing even the drought period the water has to be drained out to this areas. Certainly, streamflow of Phetchaburi river has to be decreased until it cannot be utilized to dilute the wastewater from communities along riverbanks and agricultural activities that making stream pollution in summer period. Moreover, the diversion dam of Kaeng Krachan storage dam, named as Phetchaburi diversion dam, has its own function not only diverting water to feed on mainly paddy fields in lowlands and to feast the river flow but also providing waterworks of well-known Hua Hin tourist area. In other words, the stream pollution of Phetchaburi river would be occurred for some period of time due to water from Phetchaburi diversion dam that concerning with only to paddy fields in Phetchaburi province and Hua Hin the tourism area (Chunkao, 2008). Conceptually, the Phetchaburi river pollution should not be occurred if the Phetchaburi diversion dam managing unit was well planned for distributing water to feed the double-crop paddy field, Hua Hin Waterworks, and Phetchaburi river for maintaining sustainable aquatic ecosystems under optimized benefits each other. In the same manner, wastewater from households, communities, municipals, industries, livestocks, and cropping areas has to be treated before draining into Phetchaburi river (Valipour *et al.,* 2009; DOPC 2010, 2013; Chunkao *et al.,* 2012).

OBJECTIVES

This study aimed at the contaminated toxicants in Phetchaburi river can be treated by draining more quantitative and better qualitative water from Kaeng Krachan storage reservoir through Phetchaburi diversion dam for not only releasing water to feed double-crop paddy fields, and Hua Hin tourist city but also for feeding Phetchaburi river in order to dilute organic and in-organic wastes from human settlement along the riverbanks. Besides, the dilution process is expected to receive the effective measures of handling water flow from Phetchaburi diversion dam in both wet and dry periods. The specific objectives were as follow:

1. To study on the water management in upstream of Phechburi diversion dam for irrigation system and maintaining sustainable abundance of environment and ecosystem condition in downstream of Phetchaburi river.

2. To analyze and study on the water quality parameter such as temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), Fecal coliform bacteria (FCB), total coliform bacteria (TCB), nitrate-nitrogen (NO_3-N), total dissolved solid (TDS), electrical conductivity (EC) and Ammonia-nitrogen (NH_3-N) in the study site.

3. To study and compare on the using fresh water (stream flow) in upstream of the Pethcburi diversion dam to dilute water quality in downstream of Phetchaburi diversion dam of Phetchaburi river Thailand.

Research Framework

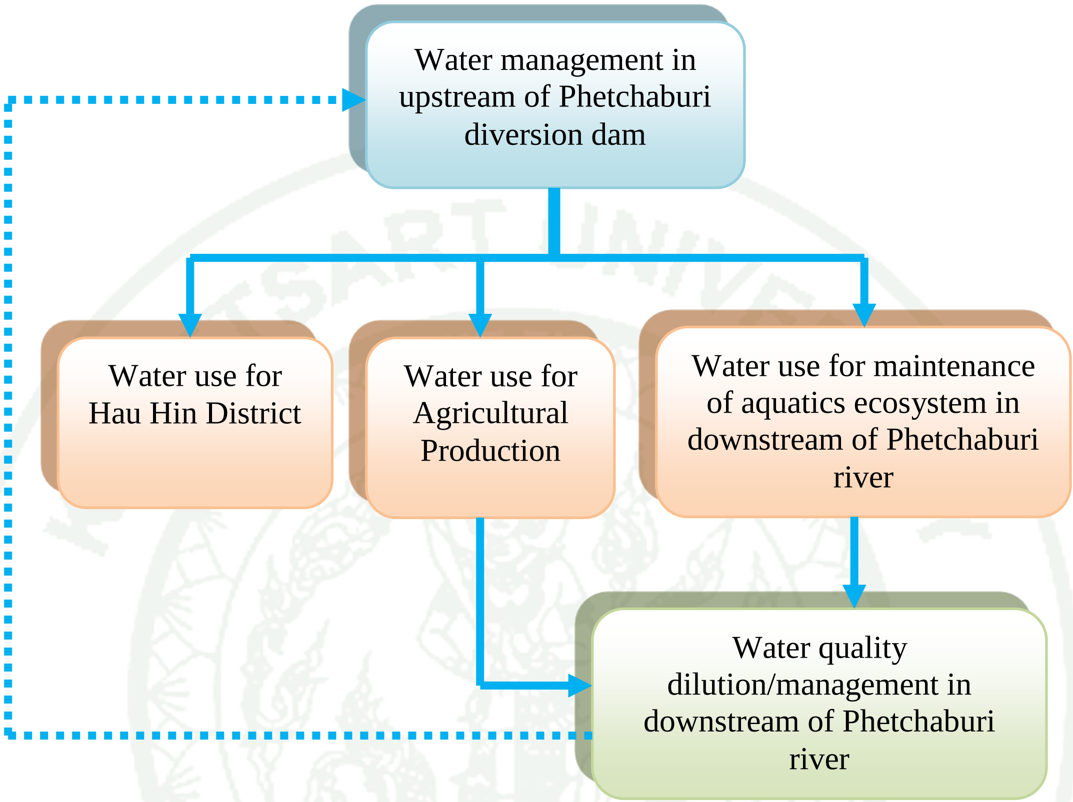


Figure 1 Conceptual framework of study

The study on the watershed management for controlling water quality in downstream of Phetchaburi river, which has conceptual framework for this study and focused on water management in upstream of Phetchaburi diversion dam include water management of Kaeng Krachan reservoir, water use for Hau Hin District, water use for agricultural production and water use for maintaining aquatics ecosystem in downstream of Phetchaburi river. Then study on dilution processes of water quality in downstream of Phetchaburi river by streamflow from Phetchaburi diversion dam in order to maintain and conserve ecosystem condition, if there is well-planned management in upstream has influence to the water quality indicators of Phetchaburi river, addition to water management at Phetchaburi diversion dam is very important in order to dilute water quality as well as the appropriation management of watershed irrigation area in the Phetchaburi watershed.

Phetchaburi Watershed Location and Characteristic

1. Location of Phetchaburi Watershed

Phetchaburi watershed is located only in Phetchaburi province, the central part of Thailand, between the latitude 12’42' to 13’ 38' N and longitude 99’10' to 100’ 08' E, the highest elevation of 1,202 m MSL down to the outlet at the Gulf of Thailand by covering total area of 5,692 sq. km (1,423,000 acres) including reservoir 46.5 sq.km (11,625 acres). The total area of watershed has been classified into forest 51 %, upland cropping 31%, paddy rice field 13%, community 4.51%,water sources 4%, and others 1% as determined by (LDD, 2011). For convenience of study, the watershed can be divided into headwater (2,210 sq.km), middle land (1,324 sq.km), lowland (1,028 sq.km), and sea coast (1,040 sq.km) but it was taken in 3 sections in the concept of riverine systems from lower Phetchaburi diversion dam to the outlet, that is, agriculture, city, and estourine zones. There are 4 sub-watersheds which is named as Huai Banklai, Huai Mae Pradon, Huai Pak, and Huai Mae Prachan streams as seen in Figure5. In fact, the headwater is located inside of Kaeng Krachan National Park about 2,915 sq.km which has been established in June 1981 while Kaeng Krachan dam togather with reservoir capacity 710 MCM in 1966. The Phetchaburi watershed is located in the Western part of Thailand, it is middle size and has been covered majority of Phetchaburi province, the Phetchaburi river is main river which length 227 Km, the watershed area is 5,692 km^2 or about 3.6 million Acres. In the watershed area is consisted with Kaeng Krachan national park is 28th National Park in Thailand. It is the largest national park in Thailand, with 2,914.70 sq.km of forest in the watersheds of the Phetchaburi and Pranburi rivers. It includes portions of Nong Ya Plong, and Kaeng Krachan districts in Phetchaburi Province and of Hua Hin district in Prachuap Khiri Khan Province, and there is Kaeng Krachan Reservoir an area of 46.5 square kilometres. Which general of Petchaburi watershed as showed in figure 2.

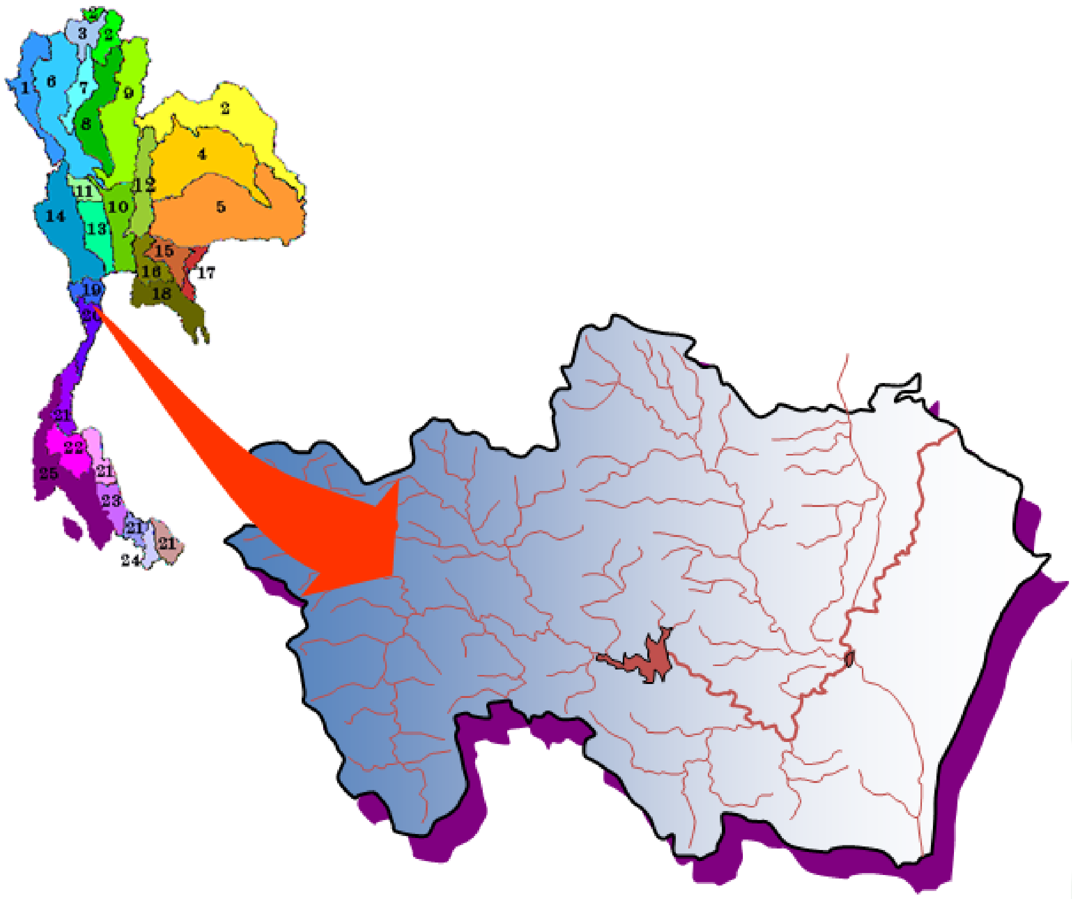


Figure 2 Map of Thailand and Phetchaburi watershed location.

Source: Modified from PCD (2002)

However, the Kaeng krachan reservoir was created by the construction of the earth dam which blocked the Phetchaburi River, that is a major river of the watershed and headwater from mountain range on the western side of the Kaeng Krachan district and there is border between Thailand and Myanmar. Areas are gradually slope down to the east in the Tha Yang district. Phetchaburi River flows through Kaeng Krachan dam and Phet diversion dam and flow into gulf of Thailand at Ban Laem District, Phetchaburi province. Which has total length of river about 227 Km, and flow capacity from 250 to 390 million m^3/s, the average slope about 1: 800 through mouth of Phetchaburi river.

Table 1 Details of provinces in Phetchaburi watershed area

Province	Province (Km^2)	Phetchaburi watershed Area		% of Province	% of Phetchaburi Watershed area
		Km^2	Acres		
Prachuap Khiri Khan	6,421.75	80.87	50,544	1.26	1.29
Phetchaburi	6,168.41	5,424.63	3,390,396	87.94	86.73
Ratchaburi	5,193.42	577.2	360,749	11.11	9.23
Samut Songkhram	414.15	171.75	107,341	41.47	2.75
Total	18,197.73	6,254.45	3,909,030		100.00

Source: Modified from HAII (2013)

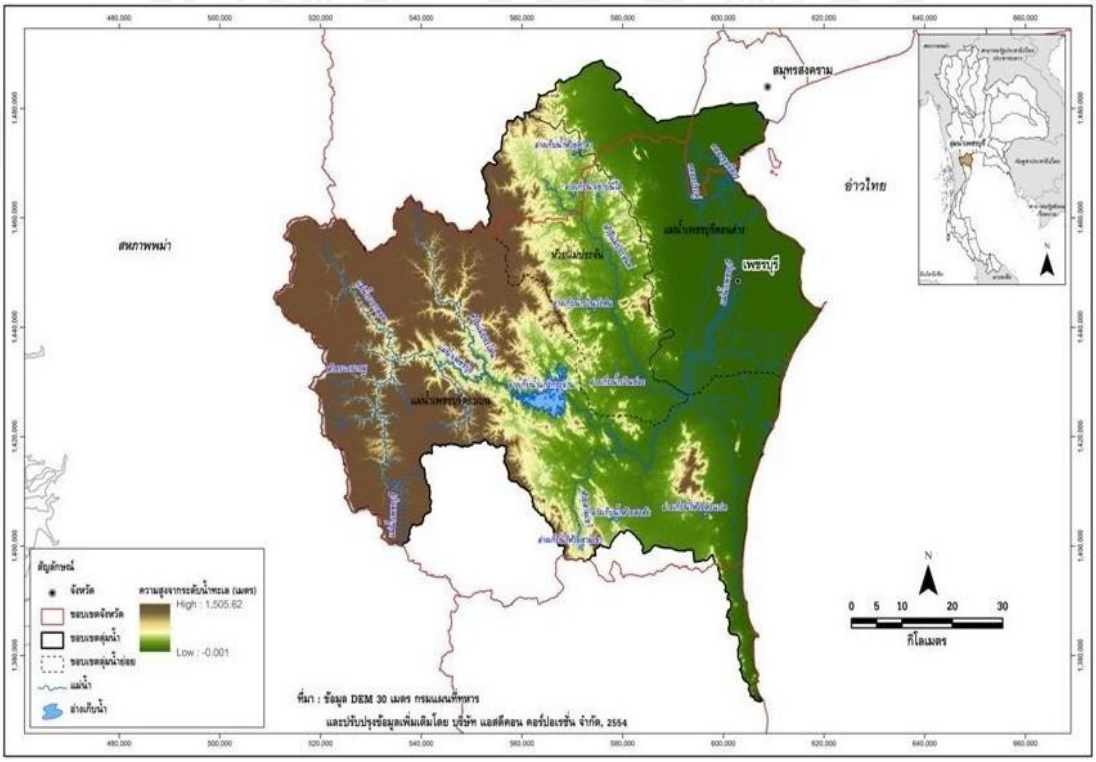


Figure 3 Map of topography and branch river in Phetchaburi watershed

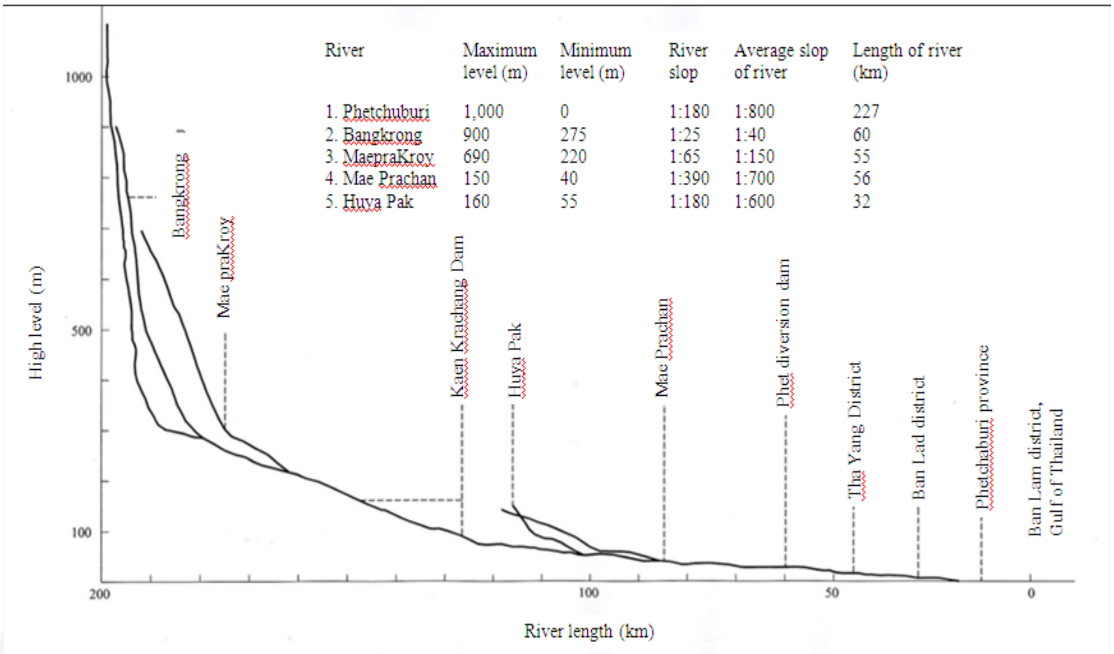


Figure 4 Characteristic of Cut along the length of the river in Phetchaburi watershed

Source: Modified from HAII (2013)

2. Characterization of Phetchaburi Watershed

There are two sub-watersheds of Pechburi watershed, Huai Mae Pradone and Huai Banklai, are naturally discharged the averaged surface water to the Kaeng Krachan reservoir 138.02 MCM/month (ranging 57.10 - 223.41 MCM/month) excluding unaccountably quantitative amount of subsurface flow from saturated forested soil zone (Chunkao 2008, Chunkao et al 1981, Baver 1968 and Baver et al 1972). Accordance with Kaeng Krachan storage dam has been constructed for mainly irrigation by using Phetchaburi diversion dam for distributing water to double-crop rice fields and another water-demand economic plants by Q1, Q2, and Q3 for paddy, Q4 for Phetchaburi river (about 80-km long from Phetchaburi diversion dam to river mouth), and Q5 for Hua Hin district (beach tour area) as shown in Figure 5. Actually, the water quantity is continuously released from Phetchaburi diversion dam to control flow regime of Phetchaburi river (Q4) and waterworks of Hua Hin district (Q5) under the demanded irrigated water to feed the paddy fields and also during water shortage.

In terms of stream pollution, it is usually happened in dry period due to irrigate much more quantity to double-crop fields for growing rice. Consequently, Phetchaburi river becomes stream pollution for such period (November to early April) until the wet season comes (late April to October). However, the climatic characteristics of Phetchaburi watershed has been classified as tropical rainforest in higher elevation, particularly headwater area, and normal tropical zone. It is acceptable that there are a lot of permanent settlement of communities, municipals, and households along the riverbanks of Phetchaburi river which has been functioned as point sources of organic wastes, toxic and non-toxic chemicals, oil and grease, debris, and microorganisms to deteriorated streamflow one way or another. The experiment of dilution process for better water quality control was possible to keep streamflow of Phetchaburi river clean enough to use for waterworks, households, and ecosystems servicing.

The major characteristic of rivers in Phetchaburi watershed area are short streams and rivers which flow to gulf of Thailand. the main Phetchaburi watershed is devised 3 tributaries such as tributary watershed of upstream Phetchaburi river or watershed area of main Phetchaburi river in upstream of Phetchaburi diversion dam. It has area about 3,508 Km^2, the major area around Kaeng Krachan reservoir is quite high slope approximately 35% and highest mountain level 700 m, the downstream watershed area of Kaeng Krachan reservoir to Phetchaburi diversion dam many short tributary rivers, inflow capacity about 120 m^3/s and average slope approximately 1:600.

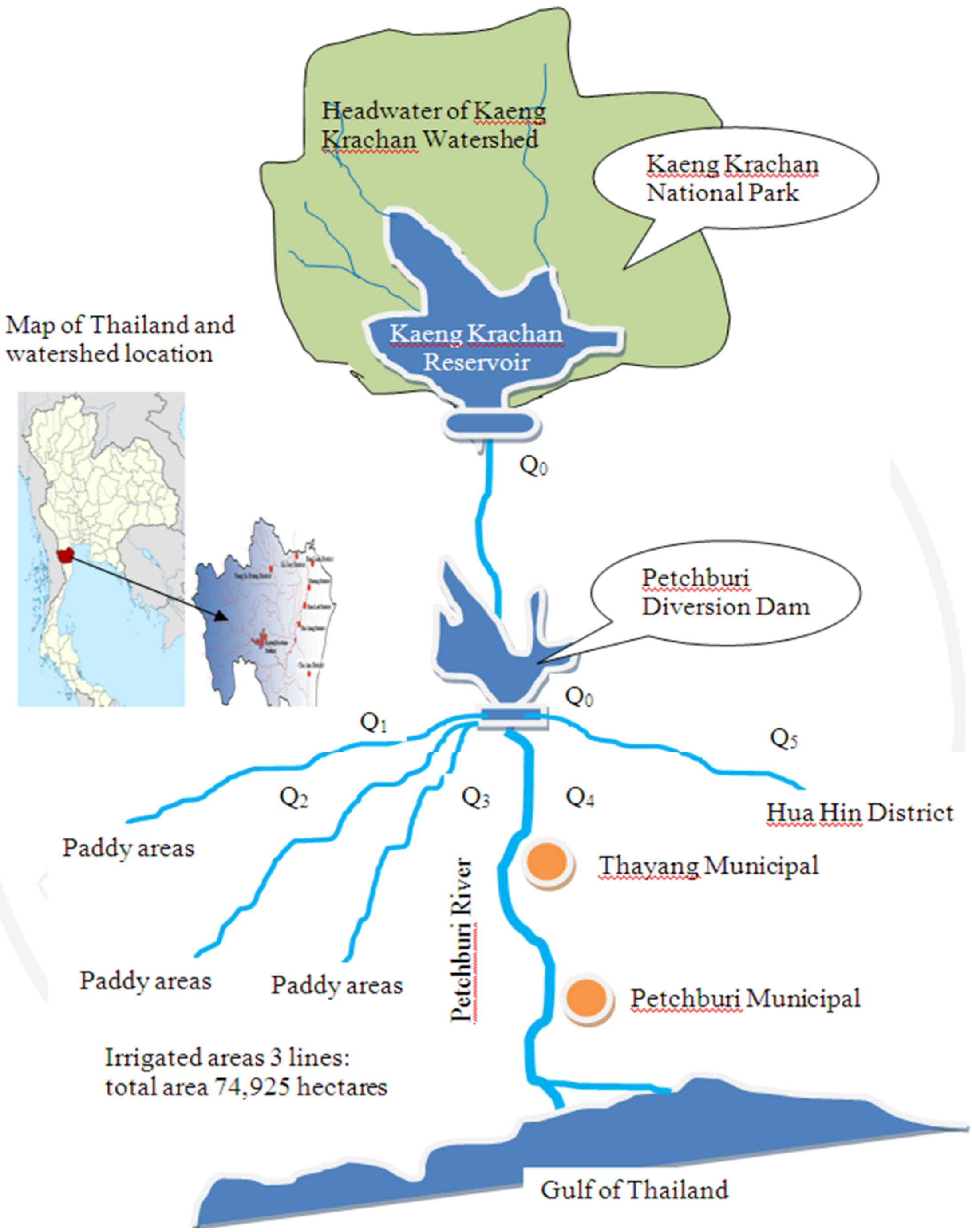


Figure 5 Characteristic of Phetchaburi watershed including four streamlets for inflow water from Kaeng Krachan National Park as headwater through Kaeng Krachan reservoir to r diversion dam before draining out to feed the five irrigation canals plus Phetchaburi river.

On the other hand, The tributary watershed of downstream Phetchaburi river which has area about 1,593 km^2 and it is quite plain area, is high average area about 5 m, it is suitable land for agricultural land, and the tributary watershed of Huay Maeprachan has area about 1,152 Km^2, the main river is Huay Mae Prachan, it is length about 56 km, inflow capacity approximately 480 m^3/s , and average slope about 1:700. The tributary watershed classification of Phetchaburi referred to study result of survey and design project on meteorology station of 25 main watersheds of Thailand of Water Resources Department (2005). Which details of location and areas of tributary watershed in Phetchaburi river as showed in table 2 and figure 6.

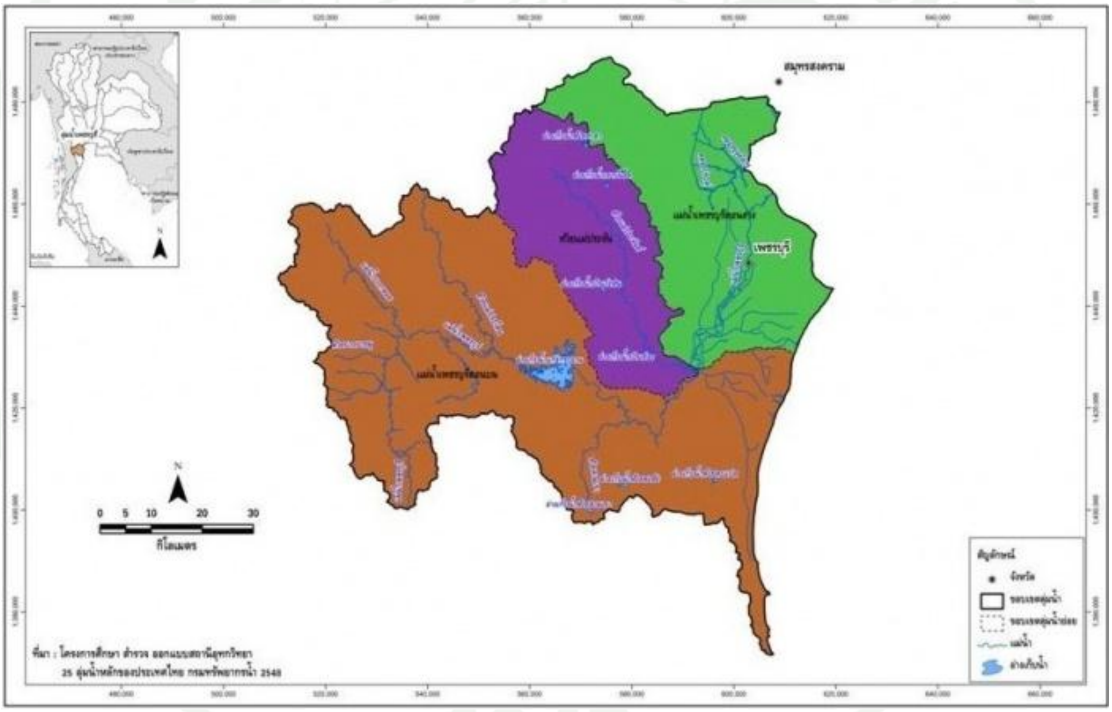


Figure 6 Tributary watersheds in Phetchaburi river

Source: Water Resources Department (2005)

Table 2 Tributary watershed and rivers characteristics of Phetchaburi river.

No	Code	Tributary watershed	Watershed area		% of Phetchaburi watershed	Province	Governing area district
			Km2	Acres			
1	1902	Upstream of Phetchaburi river	3,508.36	2,192,725	56.09	Prachuap K.Khan	Praburi and HuaHin
						Phetchaburi	KaengKrachan, ChaAm, Thayang, Nongyapong
						Ratchaburi	King of Ban Ka district
2	1903	Houy Mae prachan	1,152.14	720,089	18.42	Phetchaburi	Kaeng Krachan,Kao yoi, Thayang, Banlad, Nongyapong
						Ratchaburi	King of Ban Ka district, P.thor
3	1904	Downstream of Phetchaburi river	1,593.95	996,217	25.49	Phetchaburi	Kaeng Krachan, Kao yoi, Thayang, Banlad, Ban lam, Phetchaburi, Nongyapong
						Ratchaburi	Pakthor
						Samut S.khram	Muang samut songkran, Ampra
		Total	6,254.45	3,909,031	100		

Source: Water Resources Department (2005)

3. Climatic Characteristics

General the climate of Thailand, is defined as humid tropical which is influenced by the seasonal monsoon and the country's geographical position. The Indochinese Peninsular is part of the Asian landmass the extrudes between two great ocean bodies-the south China Sea of the Pacific Ocean and the Andaman Sea of the Indian Ocean. While the Peninsular South is bounded by seas on both its east and west shores, the main land is also in comparatively close proximity to two large bodies of water-the South China Sea to the east, and the Andaman Sea plus the Bay of Bengal to the west. The monsoons, resulting from the seasonal differences in temperatures between the landmass and the oceanic body, alternately blow in the southwesterly and northeasterly directions over Thailand.

According to the Meteorological department (2009) illustrated that The Phetchaburi province is located the gulf of Thailand, therefore it is influenced by the southwest monsoon winds, and the rainfall data is recorded from 1982 to 2008 that average rainfall was 2,129.89 mm/year, average temperature was 28.02°C, average humidity was 75.98%, average evaporation rate was 108.60 mm/month, and average wind speed was 2.41 knots in the Phetchaburi watershed area. However, the Phetchaburi province has 3 seasons including summer season is started from mid-February to mid-May, rainy season is started from in mid-May to mid-October, and winter is started from mid-October to mid-February as showed in table 3.

Table 3 Climatic statistic in Phetchaburi Province 1982 – 2008

Items	Summer				Rainy season				Winter				Year
	Feb	Mar	Apr	May	June	July	Augt	Sept	Oct	Nov	Dec	Jan	
Temperature(C)													
Maximum	33.1	34.2	35.1	36.1	35.6	35.6	35.4	34.8	33.9	33.6	33.3	33.1	**34.5**
Minimum	19.4	21.2	23.5	24.3	24.2	23.7	24.1	23.5	22.6	20.1	17.0	17.3	**21.7**
Average	26.9	28.3	29.5	29.6	29.3	28.9	29.0	28.4	27.9	27.1	25.7	25.8	**28.0**
Rainfall (mm)													
Rain day	1.0	2.7	3.5	10.5	12.3	13.7	14.9	16.1	16.9	6.4	1.4	0.9	**100.2**
Average rainfall	100.0	918.3	893	2601.7	2406.3	2172.5	2406.9	4176.9	7065.6	2223.8	331.7	262.0	**2129.9**
Humiddity (%)													
Average	76.2	76.9	75.6	75.9	74.9	75.5	75.5	79.5	81.0	76.0	71.0	73.9	**76.0**
Evaporation													
(mm/month)	115.5	136.5	143.7	124.3	112.2	107.3	102.3	98.7	88.2	90.4	88.6	95.5	**108.6**
Wind (Knot)													
Average speed	3.6	5.0	4.1	2.7	2.1	1.9	1.8	1.3	1.2	1.4	1.6	1.8	**2.4**

Source: Modified from MD (2009)

4. Soil Characteristics

According to Office of Soil Survey and Land Use Planning (2007) stated that soil series group characteristic in the Phetchaburi watershed area as show in the figure 7. The m1 soil.series group was black clay or gray that occurred from original material of river sidemen could find it in the along the mountain area of limestone or volcanic stone. The m2 soil series group, soil content was clay and top soil was gray, which found it along major plain area of central part. The m3 soil series group was much acid soil, which occurred from mixture between river sidemen and sea sidemen and could find it in along downstream of central part or plain area along shores such as Rangsit area and Don mouang area. The m5 soil series group was clay that occurred from river sidemen in the plain area and some time could find concentration of snail cover and lime in soil, the soil series in this area included Rachaburi, Bangkok, Samut Prakan, Chachoengsao and Singburi. The m8 soil series group was clay or sandy clay loam, the soil in this area such as Thachin. The m9 soil group was sandy loam to dry sandy clay loam, the soil in this area included Maesay area, Lomsak, Mae tha, Lablae, Srithab and Phanthong. The m13 soil group was shallow soil and occurred from river sidemen that moved to heaping gravel level or rubble, could find in plain area along embankment and it was in Phen and MuangKom. The m19 soil group was sand more than 50-100 cm from surface, which it occurred from dilution of hard stone or original materials such river sidemen and could find it in the quite plain area and such as NamPhong, Chanthouk and Khambong. The m20 soil group was shallow soil and gravels, rubbles in the Tha Yang area. The m21 soil group was clay or much rubble loam mixture and occurred from decomposition of stone and gravel that areas were undulate along the mountain. The m24 soil group was gravel level, rubbles or rock fragment that decomposed in the area or movement come from heaping on the stone class and it was in the Lad Ya and Phon Gyang. The m34 consisted by mountain area that has abundant of natural resources in each type of original stone in that area, there were rock fragment, gravel or stone that distributed in that area but major area was covered by forest.

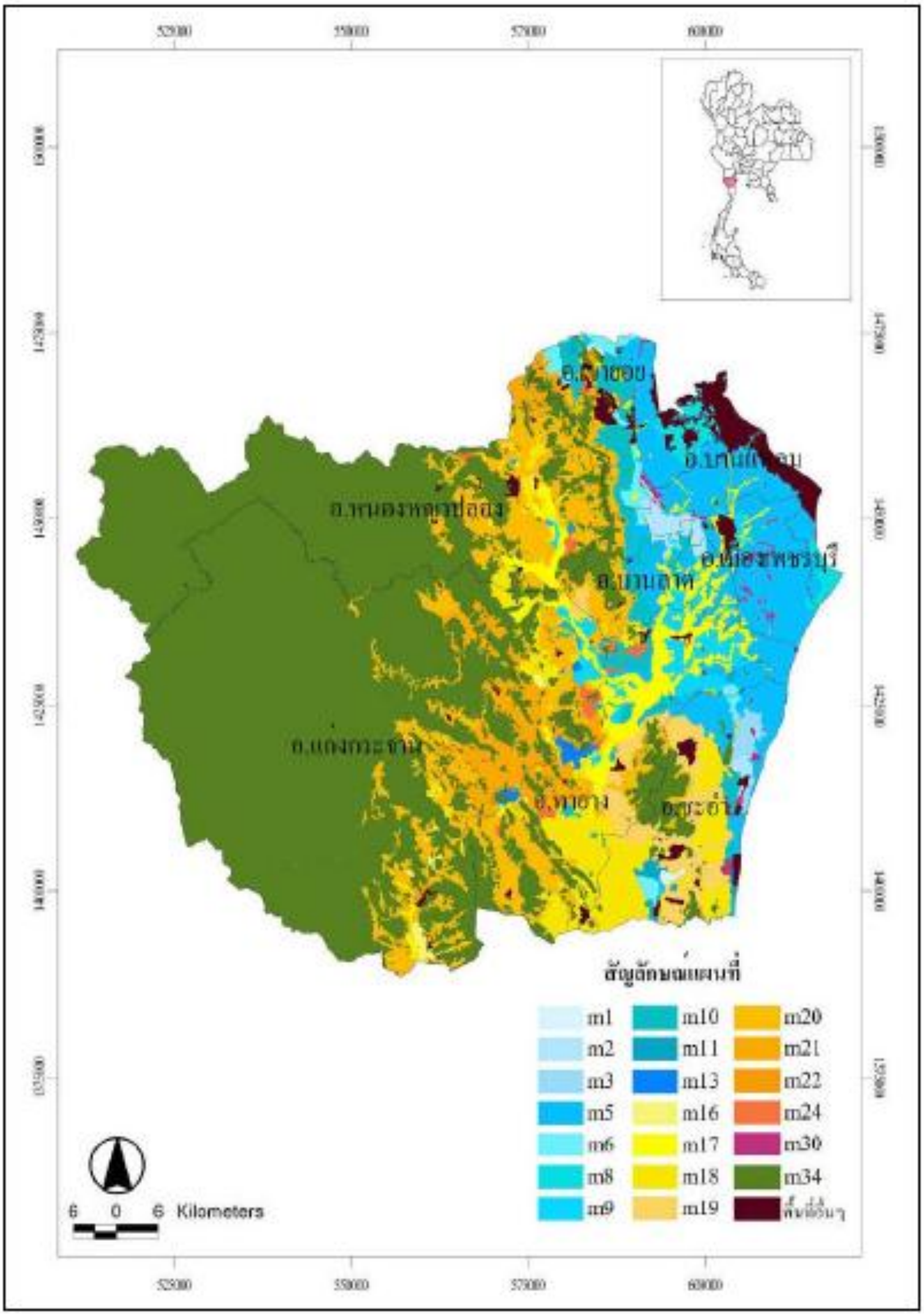


Figure 7 Map of soil group in Phetchaburi province

Sources: Modified from Office of Soil Survey and Land Use Planning (2007)

5. Forest Resources

The Phetchaburi province had forest area about 2,397,600 Rai equals 61.62 % of the total province area (about 3.89 million acres). In 2004, the Phetchaburi province had forest area 2.07 million Rai or approximately 53.21 % of total area of the Phetchaburi province. There were 15 national conservation forests and they had 2.40 million Rai, there was 1 national park such as national park of Kaeng krachan and it had area about 1.82 million Rai, this national park had largest area in Thailand**.** In addition to, there were also 2 parks such as Cha Am park and Khaonangphanturad park (Department of National Park and Wildlife, 2004). The detail as showed in figure 8.

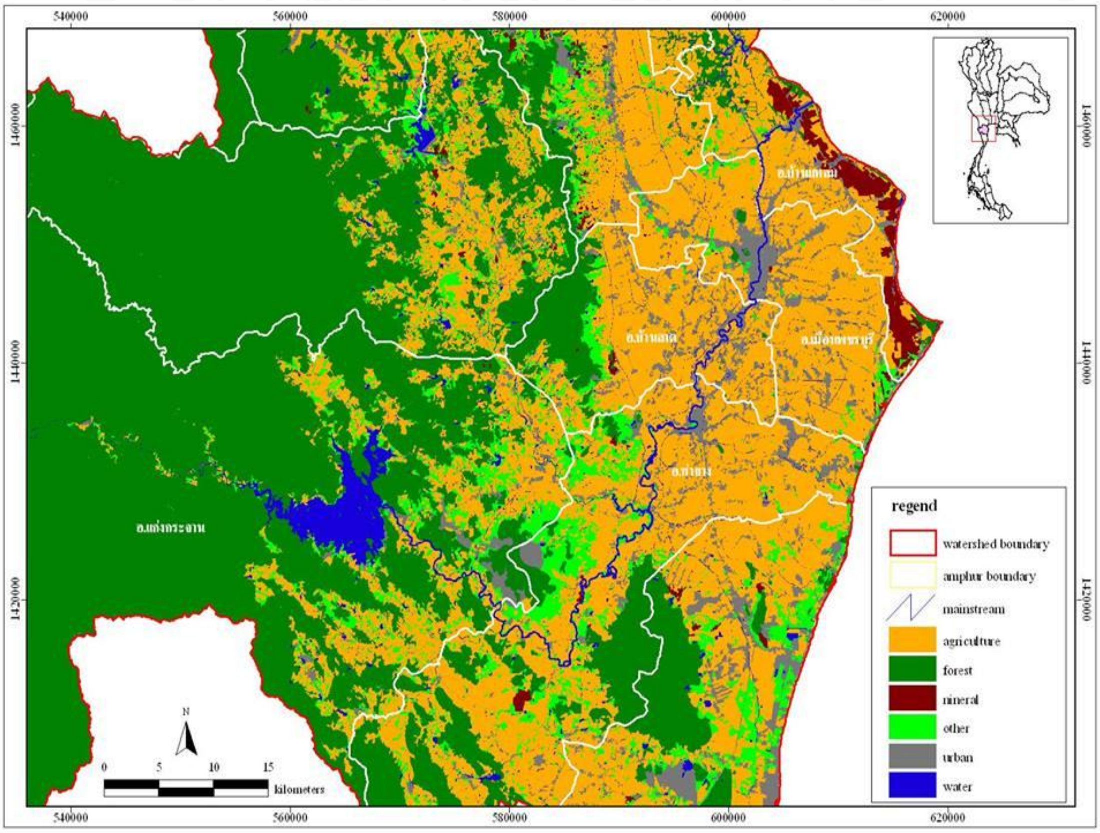


Figure 8 Map of Land use and forest cover of Phetchaburi watershed

Source: Modified from Office of Soil Survey and Land Use Planning (2007)

6. Water Resources Development Projects

According to report on investment development and water resources management plan and irrigation potential, 2009 - 2011 of committee on the water resources development and management and Irrigation stated that the water resources development projects that potential in the Phetchaburi basis area, it showed in table 4 below:

Table 4 Number of water resources development project of departments 2009- 2011

No	Water resources development project in Phetchaburi basin	RID	DOWR	Department of Wildlife & plant park
1	Rehabilitation of natural water resources		4	
2	Operation & maintenance system	1	9	
3	New storage sources development	21	10	
4	Water drainage and distribution systems	16		
5	Water diversion system	1		
6	Water resources reservation systems		3	3
7	Flood protection system	15		
8	Monkey cheek system	1		
	Total	55	26	3

Noted: Department of Irrigation (DOI); Department of Water Resources (DOWR)

Sources: Modified from department of Irrigation (2011)

7. Land Use Characteristics

According to study on the land use of land development department 2002 and 2009 in the Phetchaburi watershed. In 2009, the study result found that the most of watershed area was forest, it was 2,070,057 Rais and about 52.96% of all of the watershed area, which it decreased a little from 2002, but the proportion of total forest area is considered to be quite good condition as illustrated in table 5. Addition to, in 2011, in general, the land use of phetchaburi province changed some sectors if compared with various years, the communities and infrastructure areas were 175,112 Rais equal 4.51%, agricultural land 1,127,949 Rais about 28.97%, forest area 2,259,375 rais 58.08% of total area, water resources area 78,469 rais 2.02%, and other area 249,806 rais equal 6.42% of total area of Phetchaburi province. As it was showed in figure 9, 10 and 11 on the graph and Map of Land use below:

Table 5 Change in land use of Phetchaburi watershed

Type of land use	2002		2009		Remark
	Area (Rai)	%	Area (Rai)	%	
Rice farm	583,032	14.92	516,823	13.22	declined
Vegetable	494	0.01	19,349	0.49	increased
Upland plantation	236,905	6.06	225,132	5.76	declined
Fruit-cash tree	286,808	7.34	358,097	9.16	increased
Other agriculture	76,603	1.96	124,850	3.19	increased
Forest	2,266,224	57.97	2,070,057	52.96	declined
Other crop	458,966	11.74	594,723	15.21	increased
Total	**3,909,032**	**100**	**3,909,031**	**100**	

Source: Modified from LDD (2009)

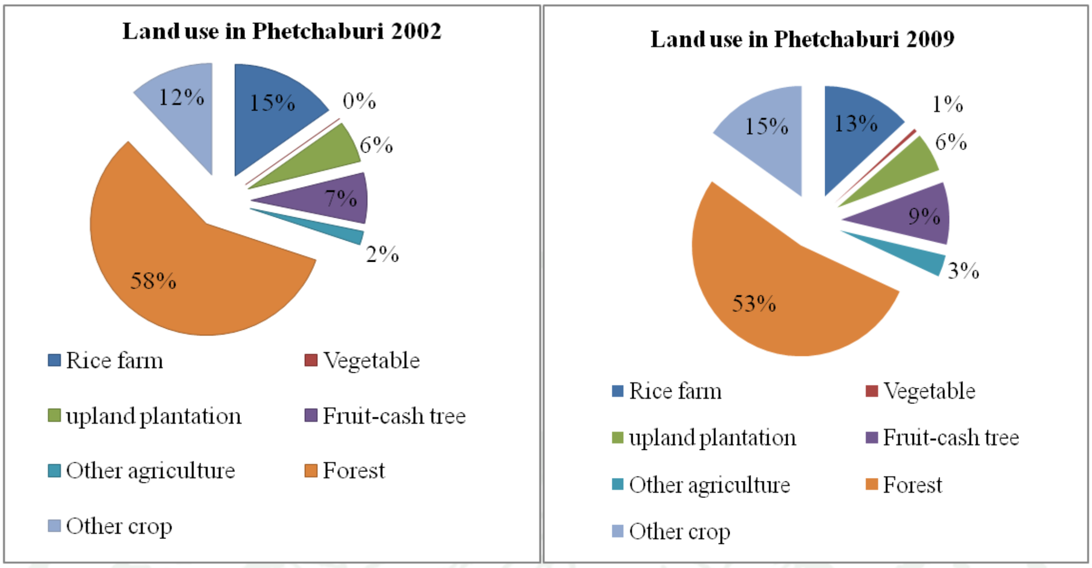


Figure 9 Land use in Phetchaburi watershed area

Sources: Modified from LDD (2009)

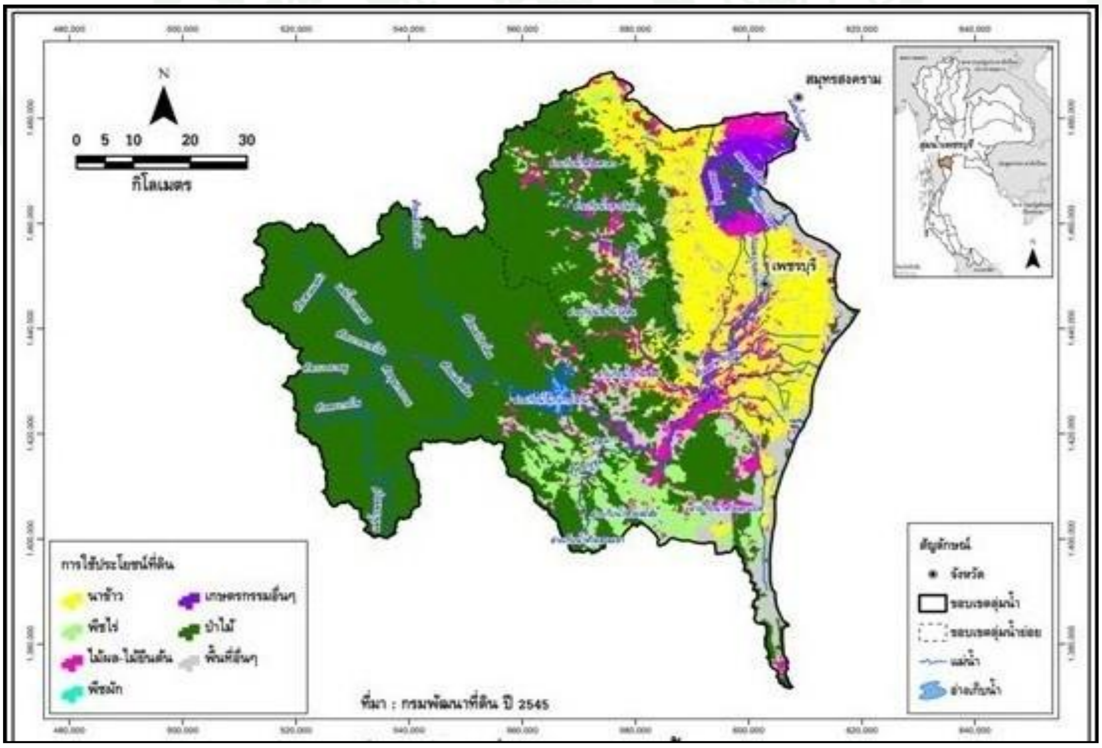


Figure 10 Map of Land use in Phetchaburi watershed 2002 and 2009

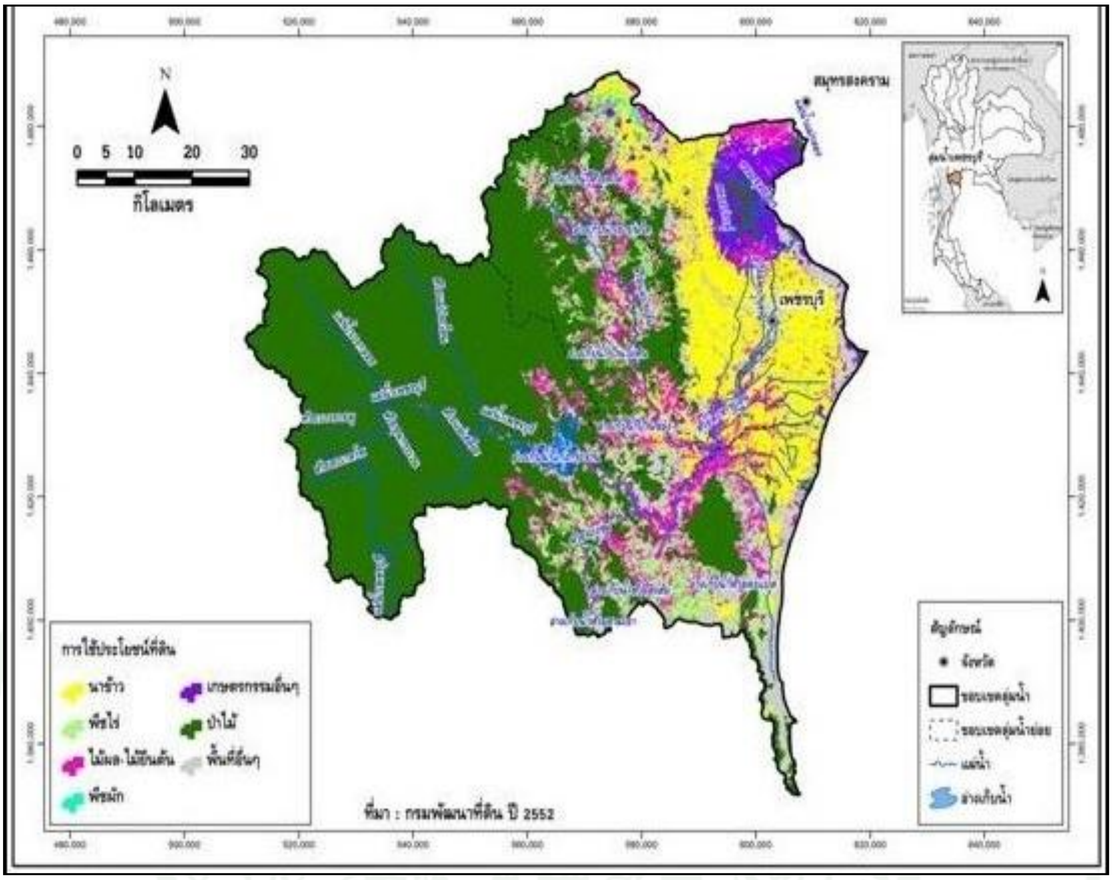


Figure 10 (Continued)

Source: Modified from LDD (2009)

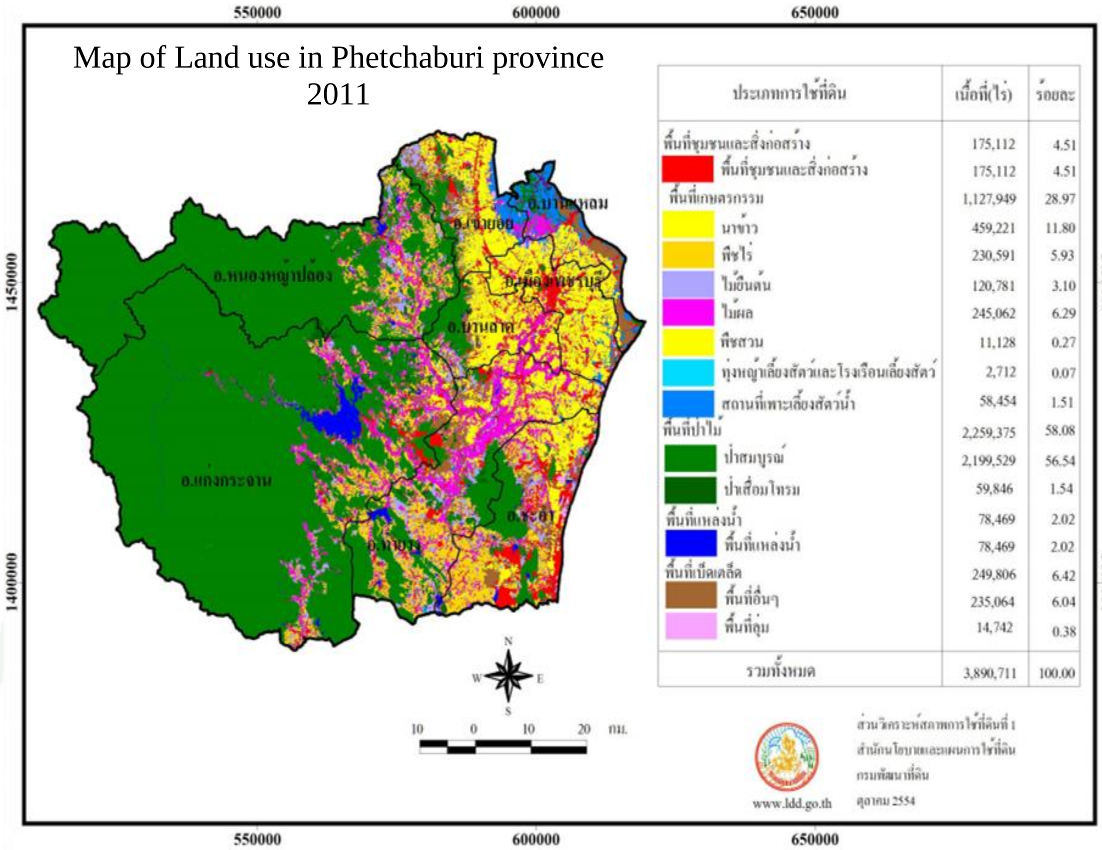


Figure 11 Map of land use of Phetchaburi province 2011.

Source: Modified from LDD (2011)

8. Population Characteristics

According to the Department of Community Development, (2009) indicated that population were 508,623 people in Phetchaburi watershed areas, and there were male and female 246,552 and 262,071 people respectively, there were140,758 households and population average 4 people/household, the people could be labor 308,222 people and average about 2 people/household, it was 60.60 % of all population in that areas. And also the most of people live in Phetchaburi province more than other provinces, which there were 411,346 people and about 80.87 % of all population.

9. Economic and Social Condition

According to LDD (2009) showed that economic and social data in Phetchaburi watershed area is consisted 4 provinces including Samut Songkhram, Ratchaburi, Phetchaburi, Prachuap Khiri Khan Province, 12 districts, 101 sub-district/ municipalities and 594 villages. Details of socio-economic development are indicated in the table 6.

Table 6 Population, economic and social condition

No	Content	Unit	Phetchaburi Province	Percentage (%)
1	**Agricultural activities**			
	Farm	Rai	351,820	75.13
	Upland farm	Rai	199,256	42.55
	Plantations	Rai	107,850	23.03
	dry season production	Rai	27,340	5.84
	Livestock	Household	6,073	5.91
	Fisheries	Household	1,257	1.22
	Aquatic livestock	Household	567	0.55
2	**Average income**	B/h/year	1,756,482	
3	**Workers**	B/h/year	21,682	
4	**Industrial sector**			
	Factory	Place	91	
	Household business	Place	906	
	Rice mill	Place	163	
	Electric available	Village	561	
	Water supply available	Household	48,008	46.68
	Public telephone	Units	820	
	Access road	Village	551	
5	**Water & natural resources**			
	Drinking water sufficiency	Household	58,332	56.72
	Water use sufficiency	Household	57,819	56.22
	Agricultural water insufficiency	Rai	76,539	16.34

Source: Community Development Department (2009)

LITERATURE REVIEW

This chapter is reviewed on the watershed management and water quality, many constituents have been examining when determining the quality of surface waters. Constituents include physical, chemical, and microbiological characteristics of water, and examined the background of water pollutants, regulations regarding surface waters, and factors affecting surface water quality as well as point sources and point effect of the water quality.

1. Definition of Watershed

There are many experts and scientists defined on the watershed, a watershed is the area of land that drains into a body of water such as a river, lake, stream or bay. It is separated from other watersheds by high points in the area such as hills or slopes or by contour line. It includes not only the waterway itself but also the entire land area that drains to it. The surface area bordered by rise in elevation of land, where water is gathered and drained into a water body such a marshland, watercourse or lake. The concept is also used, to refer to a river basin, catchment area or drainage basin (Pereira, 1973). Drainage basins generally refer to large watersheds that encompass the watersheds of many smaller rivers and streams. Watershed is a area unit, which covered by natural rivers and water storage flow to a river, each watershed has unstable size depend on the geography condition and purpose of watershed management (Chunkao, 2008). In addition, a watershed, also called a drainage basin or catchment area, is de1ned as an area in which all water flowing into it goes to a common outlet. People and livestock are the integral part of watershed and their activities affect the productive status of watersheds and vice versa from the hydrological point of view, the different phases of hydrological cycle in a watershed are dependent on the various natural features and human activities. Watershed is not simply the hydrological unit but also socio-political-ecological entity which plays crucial role in determining food, social, and economical security and provides life support services to rural people (Wani *et al*., 2008).

2. Principle of Watershed Management

The efficiency of the watershed management can keep the efficient and sustainable watershed situation by prevention on the unsuitable natural resources utilization to the principle of watershed management, the observation on the application and rehabilitation of natural resources degradation and maintenance for the recovery to normal condition, all of these related with the watershed management activities and relevant with the sustainable water quality management in the watershed area (Chunkao, 2008). And also the watershed management is the study of the relevant characteristics of a watershed aimed at the sustainable distribution of its resources and the process of creating and implementing plans, programs, and projects to sustain and enhance watershed functions that affect the plant, animal, and human communities within a watershed boundary (Anderson, 1999).

In addition, the principle on the watershed management included 4 stages, first the land use planning/watershed classification, second watershed resources utilization and natural resources conservation control measures, third waste and pollutants control in environment, and fourth are activities control in the management system (Chunkao, 2008). Features of a watershed that agencies seek to manage include water supply, water quality, drainage, storm water runoff, water rights, and the overall planning and utilization of watersheds. Due to their complexity, managers and planners have traditionally managed watersheds to optimize only one or a few resources. A more holistic approach is needed that addresses watershed resources and other components while stressing the importance of maintaining the sustainable uses of all the resources within a watershed (Tecle *et al*., 2003 and Buller, 1996).

However, principle of watershed management have to take into account structures and functions of watershed system should be normal situation in terms of physical, biological, human use values and life quality values resources including management about quantity, quality, timing flow of rivers, and lakes as well as soil erosion, flood and resources utilization but integrated watershed management is best approach (Chunkao, 2008). In addition, the managing a watershed involves not only individual plots, but also common property resources like forests, springs, gullies, roads and footpaths, and vegetation along streams and rivers (Kerr, 2002). The needs and priorities for different users are different in each watershed. By seeking information from farmers about their constraints and priorities, their potential for new technologies, appropriate policies and technology can be designed for each watershed. Therefore participatory watershed management involves all actors to jointly discuss their interests, prioritize their needs, evaluate potential alternatives and implement, monitor and evaluate the project outcomes (Azene and Gathriu, 2006).

3. Watershed Functionality

A watershed is an area of land where all of the water that is under it or drains off of it goes into the same place (Dwight *et al*., 2011). Watersheds include and connect all terrestrial, freshwater, and coastal ecosystems with hydrological functions that catch, store, and safely release water (Petersen, 1999). All of these functions are interrelated to make up the whole system that is a watershed (Petersen, 1999). On the other hand, function of watershed system depend on the plenty of structure environment includes four groups physical, biological, human use values and life quality environment, in addition, the function of watershed includes production, recycling and transformation systems (Chunkao, 2008). A watershed functions to carry out a number of valuable services, such as supporting biological diversity of aquatic and riparian ecosystems, supplying and purifying sources of fresh water for potable use, sequestering carbon dioxide to mitigate climate change, and supporting recreation and tourism (Postel and Thompson, 2005). It is the benefit of human society that long-term preservation and sustainability of freshwater ecosystems are maintained (Baron *et al*., 2002). Watersheds are not always contained within a state, county, or national boundaries because they come in many different shapes and sizes defined by their geographic properties such as United States (Dwight *et al*., 2011).

Petersen (1999) noted that how a watershed functions is dependent on its geomorphic component landforms, which include stream channels, floodplains, mountain slopes, ridge tops, and stream terraces, (Baron *et al*, 2002) also mentioned that the ecological benefits that watershed functions have for freshwater systems and states that native plants and animal populations are directly influenced by these watershed functions. The three fundamental functions of a watershed are: collecting water from rainfall, snowmelt, and runoff; storing various amounts over time; and discharging the water as runoff (Black, 1997). Watersheds support a diversity of aquatic life and allow important biological and chemical reactions to take place. The third watershed function, discharge, helps control and moves chemicals and materials out of the system. Well functioning watersheds are a natural benefit supplying an abundance of goods and services to society, but when these functions are only slightly disturbed by external factors, they can be altered to the extent of being unable to function properly (Elshorbagy *et al.*, 2005; Petersen, 1999; Postel and Thompson, 2005). The major functions of watersheds and how they play a role in the hydrologic cycle and ecologic environment. He stated there is an "important linkage between hydrology and water quality (Black, 1997).

In addition to, the structure and functions of freshwater ecosystems are closely connected to watersheds because they serve as the outlet of runoff pollution (Baron *et al*., 2002). Runoff in water bodies needs to travel longer distances before reaching the outlet. Peak flows of larger watersheds are lower than smaller watersheds, in terms of rate per unit area (Black, 1997), and this increase in travel time allows for pollutant concentrations to magnify. Currently, a majority of watershed management activities and programs focus on protecting water quality and mitigating land use impacts to preserve the health of watersheds (Black, 1997).

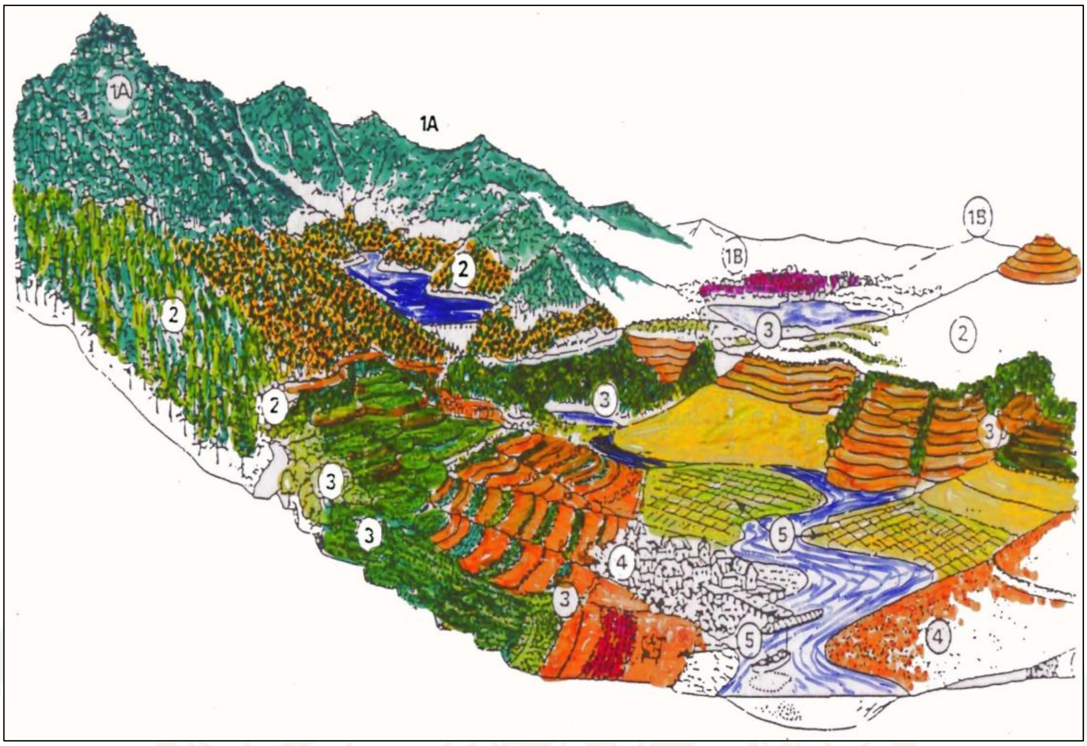


Figure 12 Pictorial guide to Watershed Classification and land use practices in Thailand. Which WSC 1A - headwater source with forest; WSC 1B - WSC 1 + agric. + village; WSC 2 - Commercial forest; WSC 3 - Commercial forest, grazing, fruit trees, agroforestry with conservation measures; WSC 4 - row crops, fruit trees, grazing + simple conservation measures; WSC 5 - paddy fields or other agricultural uses with few restrictions

Source: Modified from Chunkao (2008)

4. Water Pollution Characteristics

Water pollution is the contamination of water bodies (e.g. lakes, rivers, oceans, aquifers and groundwater). Water pollution occurs when pollutants are discharged directly or indirectly into water bodies without adequate treatment to remove harmful compounds. Water pollution affects plants and organisms living in these bodies of water. In almost of all cases the effect is damaging not only to individual species and populations, but also to the natural biological communities.

The pollutants that affect surface water quality are separated into two categories: point and nonpoint sources. Point source pollution originates from an easily identifiable pipeline discharge or location through a direct route, such as discharge from industrial facilities or sewage treatment plants. Nonpoint pollution sources on the other hand are from a variety of diffuse sources such as activities from construction, agriculture, mining, or even urban runoff (Jamwal *et al.*, 2011). Due to the numerous different sources, it is difficult to regulate and identify all the nonpoint pollution sources. Both point and nonpoint sources of pollution cause damage to aquatic life living within rivers and streams and can cause adverse effects to human health, which may lead to impaired water bodies and limits their use (Elshorbagy *et al*., 2005 and Dwight *et al*., 2011). Where many of the point sources have been controlled in past decades due to the passage of the Clean Water Act, nonpoint source pollution continue to be a major source of water pollution and remains a challenge to control (Harrington *et al.*, 1985).

According to Boyacioglu and Alpaslan (2008) pointed out that water quality management over the past three decades had initially been driven by point source pollution; however, more recent regulations promulgated by the (Dwight *et al*., 2011) include both point and nonpoint source pollution. Moreover, discharges from unregulated nonpoint sources have not been successfully controlled and most states have not met water quality goals (Boyacioglu and Alpaslan, 2008). Water pollution is a major global problem which requires ongoing evaluation and revision of water resource policy at all levels (international down to individual aquifers and wells). It has been suggested that it is the leading worldwide cause of deaths and diseases (Pink *et al.*,2006). Water pollution include heavy metals, sediment, certain radioactive, isotopes, heat, fecal coliform bacteria, phosphorus, nitrogen, sodium, and other useful(even necessary) elements, as well as certain path-organic bacteria and viruses (Botkin and Keller, 2005).

5. Water Quality Characteristics

Several studies have analyzed the effects of point and non-point sources pollution on water quality on a watershed scale. Water quality is measured by several factors, such as the concentration of dissolved oxygen, bacteria levels, the amount of salt or salinity, or the amount of material suspended in the water turbidity. In some bodies of water, the concentration of microscopic algae and quantities of pesticides, herbicides, heavy metals, and other contaminants may also be measured to determine water quality. In addition, the surface water quality in most part of Thailand can be considered as fair conditions, while some rivers flowing in large communities are adversely impacted. Water quality problems are affected by domestic and industrial wastewater discharges, agricultural point and non-point source discharges, deforestation, and development projects (Simachaya, 2000). Furthermore the river water quality is determined by measuring three aspects of river quality: biology, chemistry and physical quality, it refers to the assessment of chemical, biological quality and physical properties. In the water chemical quality, nutrients are the most important matter to be taken into consideration because of its bad effect in rivers ecosystem and these determine the status and the trends in stream and river's water quality in general (Bingham, 2006).

Water quality refers to the chemical, physical and biological characteristics of water (Diersing, 2009). It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose. It is most frequently used by reference to a set of standards against which compliance can be assessed (Johnson *et al*., 1997). The most common standards used to assess water quality relate to health of ecosystems. On the other one, water quality is a term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for an intended purpose. These characteristics are controlled of influenced by substances, which are either dissolved or suspended in water. Water quality data from each of these sub-basins for the parameters of dissolved phosphorous, dissolved nitrogen, and total nitrogen, to determine the types of land use that contributed to non-point source pollution, the concentration of each pollutant was the dependent variable and stream flow and the percent land cover for each type of land use were the independent variables (Kebede *et al*,. 2003).

6. Stream Pollution Characteristics

Recently, river water pollution has been a common problem for many regions and countries (Howarth *et al.,* 2002 and Chen *et al*., 2006). Stream water quality is strongly related to the increasing anthropogenic influences in watersheds, such as changing land use pattern, increasing wastewater discharge and fertilizer application (Xu *et al.*, 2009 and Ye *et al.*, 2009). It is well known that watershed management is an efficient way to control river water pollution (Paer *let al.*, 2004). Towards establishing an efficient watershed management system, therefore, the first step is to distinguish the relationship between the river water pollution and anthropogenic influences at a watershed scale (Dowd *et al*., 2008). Land use patterns and human activities in watershed have significant impact on the water quality characteristics in the corresponding river (Ribbe *et al.*, 2008 and Zhang *et al.*, 2009). Rivers located in the regions undisturbed by human activities often have high water quality (Ometo *et al.*, 2000 and Swaine *et al.*, 2006). In agricultural catchments, river water quality is mainly impacted by nutrients from farming systems (Borbor-Cordova *et al.*, 2006). In urban areas, however, river water quality is mainly impacted by nutrient and organic chemical pollutants from household wastewater and industrial sewage (Wang *et al.*, 2007). For a larger watershed, in general, it contains different types of catchments with different land covers and human activities (Edwards *et al.*, 2000). To understand such spatial variations, therefore, it is necessary to distinguish the water pollution characteristics for different river reaches relating to the land covers and human activities in their catchments for a watershed.

7. Water Quality Indicators

Several water quality indicators are analyzed when determining water quality of surface water sources. This section describes the parameters analyzed and their meaning. These parameters include physical and chemical constituents that were analyzed on the water samples for this thesis. Water quality indicators cause various environmental problems, most importantly the pollution of streams and groundwater limits usable water resources and destroys aquatic ecosystems.

7.1 Temperature

Changes in temperature largely affect the chemical characteristics of water. Overall increased temperatures in water bodies can cause increased chemical and biological reaction rates, mineral solubility, and growth of aquatic organisms. Tchobanoglous (1985) stated that higher temperatures also decrease gas solubility and respiration rates. Warmer waters have lower dissolved oxygen solubility. Low DO levels negatively affect plant and aquatic species within the water and change the character of a water body (APHA *et al*., 1998; Kailasam and Sivakami, 2004). Temperature also can affect the ability of water to hold oxygen as well as the ability of organisms to resist certain pollutants.

Temperature exerts a major influence on biological activity and growth. Temperature governs the kinds of organisms that can live in rivers and lakes. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have a preferred temperature range. As temperatures get too far above or below this preferred range, the number of individuals of the species decreases until finally there are none. Temperature is also important because of its influence on water chemistry. The rate of chemical reactions generally increases at higher temperature. Water, particularly groundwater, with higher temperatures can dissolve more minerals from the rocks it is in and will therefore have a higher electrical conductivity. It is the opposite when considering a gas, such as oxygen, dissolved in the water. Think about how much bubblier a cold soda is compared to a warm one. How warm stream water is can affect the aquatic life in the stream. Warm water holds less dissolved oxygen than cool water, and may not contain enough dissolved oxygen for the survival of different species of aquatic life. Some compounds are also more toxic to aquatic life at higher temperatures.

7.2 pH

The acidic or basic characteristics of a water body are described by pH (APHA, 1998). pH is measured on a scale from 1.0 - 14.0 with no unit, where more basic solutions have a higher pH and more acidic solutions have a lower pH. The pH scale measures the logarithmic concentration of hydrogen (H^+) and hydroxide (OH^-) ions (EPA, 2003b). Several factors can be affected by the pH of water, including biological availability and solubility of elements in water. Growth and reproduction of freshwater aquatic species of fish are found to be ideal within a pH range of 6.5 to 8.5; however, they may thrive slightly outside this range as well (Wilber, 1969). The ability of water to resist changes in pH is based on the buffering capacity of the water body. The water with a pH > 8.5 indicates that the water is hard; most metals become more water soluble and more toxic with increase in acidity, and toxicity of cyanides and sulfides also increases with a decrease in pH (increase in acidity). The content of toxic forms of ammonia to the un-toxic form also depends on pH dynamics (Mosley *et al.*, 2004).

On the other hand, pH is a measure of how acidic/basic water is. The range goes from 0 - 14, with 7 being neutral. pHs of less than 7 indicate acidity, whereas a pH of greater than 7 indicates a base. pH is really a measure of the relative amount of free hydrogen and hydroxyl ions in the water. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic. Since pH can be affected by chemicals in the water, pH is an important indicator of water that is changing chemically. Water with a pH of 5 is ten times more acidic than water having a pH of six. Pollution can change a water's pH, which in turn can harm animals and plants living in the water. For instance, water coming out of an abandoned coal mine can have a pH of 2, which is very acidic and would definitely affect any fish crazy enough to try to live in it. Generally, pH of rivers in world is around 7, except in estuaries. At most intake facilities the pH is around 7.0. When the pH is more than 8.5, it interferes with chlorination during water treatment plant. To ensure prevention of corrosion in the treatment plant and distribution system, maintaining pH between 6.5-8.5 is desirable. If pH is outside the above-mentioned range, it may cause irritation of eyes and adversely affects the growth of plants and marine organisms. Low pH at the roots of rice plants severely affects the plants due to the dissolution of salts, while high pH causes discoloration of leaves.

7.3 Electrical Conductivity (EC)

Conductivity describes the ability of an aqueous solution to carry an electric current (APHA *et al*., 1998). The amount of ions or total dissolved salts in water is an indicator of conductivity, meaning conductivity increases as the concentration of ions increases (Tchobanoglous, 1985). Conductivity is typically reported in microsiemens per centimeter (µS/cm). Solutions with mostly inorganic compounds tend to be better conductors while solutions with organic compounds do not conduct currents well (APHA *et al.*, 1998). The type of rock and soil within the watershed affects conductivity. Watershed size is also a factor, as contact time with the rocks and soils increases with increasing watershed size. The electrical conductivity is a function of total dissolved solids (TDS) known as ions concentration, which determines the quality of water (Tariq *et al.*, 2006). Electric Conductivity or Total Dissolved Solids is a measure of how much total salt (inorganic ions such as sodium, chloride, magnesium, and calcium) is present in the water (Mosley *et al.*, 2004). The discharge of wastewater with a high TDS level would have adverse impact on aquatic life, render the receiving water unfit for drinking and domestic purposes, reduce crop yield if used for irrigation, and exacerbate corrosion in water networks (Nadia, 2006).

However, the electrical conductivity of the water depends on the water temperature: the higher the temperature, the higher the electrical conductivity would be. The electrical conductivity of water increases by 2-3% for an increase of 1 degree Celsius of water temperature. Many EC meters nowadays automatically standardize the readings to 25^{o}C. While the electrical conductivity is a good indicator of the total salinity, it still does not provide any information about the ion composition in the water. The same electrical conductivity values can be measured in low quality water (e.g. water rich with Sodium, Boron and Fluorides) as well as in high quality irrigation water (e.g. adequately fertilized water with appropriate nutrient concentrations and ratios).

7.4 Dissolved Oxygen

The oxygen dissolved in lakes, rivers, and oceans is crucial for the organisms and creatures living in it. As the amount of dissolved oxygen drops below normal levels in water bodies, the water quality is harmed and creatures begin to die off. Although water molecules contain an oxygen atom, this oxygen is not what is needed by aquatic organisms living in our natural waters. A small amount of oxygen, up to about ten molecules of oxygen per million of water, is actually dissolved in water. This dissolved oxygen is breathed by fish and zooplankton and is needed by them to survive. Rapidly moving water, such as in a mountain stream or large river, tends to contain a lot of dissolved oxygen, while stagnant water contains little. Bacteria in water can consume oxygen as organic matter decays. Thus, excess organic material in our lakes and rivers can cause an oxygen-deficient situation to occur. Aquatic life can have a hard time in stagnant water that has a lot of rotting, organic material in it, especially in summer, when dissolved oxygen levels are at a seasonal low.

Dissolved oxygen is a measurement of the amount of oxygen gas dissolved in water, and available for use by plant and aquatic species oxygen gas naturally mixes with water through surface interaction, fast moving waters typically have a higher DO due to mixing with air when the water hits debris such as rocks and logs. Dissolved oxygen can be depleted by the demand from organic decomposition and use from plant and animal respiration (Vigil, 2003). Aquatic populations exposed to low dissolved oxygen concentrations may be more susceptible to adverse effects of other stressors such as disease or effects of toxic substances. Different varieties of fish need different amounts of DO to thrive. Based on the U.S. EPA’s water quality criteria, the one-day minimum for cold-water species is 5.0 mg/L in early development stages and 4.0 mg/L for other stages. For warm water species, 5.0 mg/L and 3.0 mg/L is needed in early and other stages, respectively (U.S. EPA, 1986).

7.5 Biochemical oxygen demand

Biological oxygen demand **(**BOD) is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. The term also refers to a chemical procedure for determining this amount. This is not a precise quantitative test, although it is widely used as an indication of the organic quality of water (Clair *et al.*, 2003). The BOD value is most commonly expressed in milligrams of oxygen consumed per litre (mg/L) of sample during 5 days of incubation at 20 °C and is often used as a robust surrogate of the degree of organic pollution of water. Unpolluted, natural waters should have a BOD of 5 mg/L or less. Raw sewage may have BOD levels ranging from 150-300 mg/L.

Most pristine rivers will have a 5-day carbonaceous BOD below 1 mg/L. Moderately polluted rivers may have a BOD value in the range of 2 to 8 mg/L. Municipal sewage that is efficiently treated by a three-stage process such as wastewater and household sewage, both runoff (effluents), domestic, and commercial and institutional would have a value of about 20 mg/L or less. Untreated sewage varies, but averages around 600 mg/L in Europe and as low as 200 mg/L in the U.S., or where there is severe groundwater or surface water Infiltration/Inflow. The generally lower values in the U.S. derive from the much greater water use per capita than in other parts of the world. (Clair *et al*., 2003).

7.6 Fecal Coliforms

A fecal coliform is a facultatively anaerobic, rod-shaped, gram-negative, non-sporulating bacterium. Fecal coliforms are capable of growth in the presence of bile salts or similar surface agents, are oxidase negative, and produce acid and gas from lactose within 48 hours at temperature of 44 ± 0.5°C (Doyle and Erickson, 2006). The term “thermotolerant coliform” is more correct and is gaining acceptance over faecal coliform (Bartram and Balance, 1996). In addition, coliform bacteria include genera that originate in feces (e.g. Escherichia) as well as genera not of fecal origin (e.g. Enterobacter, Klebsiella, Citrobacter). The assay is intended to be an indicator of fecal contamination; more specifically of *E. coli* which is an indicator microorganism for other pathogens that may be present in feces. Presence of fecal coliforms in water may not be directly harmful, and does not necessarily indicate the presence of feces (Doyle and Erickson, 2006). Potential sources of fecal coliform bacteria in water, it has in aquatic environments may indicate that the water has been contaminated with the fecal material of humans or other animals. Fecal coliform bacteria can enter rivers through direct discharge of waste from mammals and birds, from agricultural and storm runoff, and from human sewage. However, their presence may also be the result of plant material, and pulp or paper mill effluent (Doyle and Erickson, 2006)

Untreated organic matter that contains fecal coliform can be harmful to the environment. Aerobic decomposition of this material can reduce dissolved oxygen levels if discharged into rivers or waterways. This may reduce the oxygen level enough to kill fish and other aquatic life. Reduction of fecal coliform in wastewater may require the use of chlorine and other disinfectant chemicals. Such materials may kill the fecal coliform and disease bacteria. They also kill bacteria essential to the proper balance of the aquatic environment, endangering the survival of species dependent on those bacteria so higher levels of fecal coliform require higher levels of chlorine, threatening those aquatic organisms.

7.7 Nitrogen as Ammonia

In natural surface waters, ammonia occurs in two forms: ionized ammonia, NH4+, and un-ionized ammonia, NH_3^0 (Zamzow, 2009). Ammonia can be produced naturally from the breakdown of organic matter and is excreted by fish as a nitrogenous waste product. In fish, ammonia is a byproduct of protein metabolism and is primarily excreted across the gill membranes, with a small amount excreted in the urine, ammonia produced by fish can be eliminated by bacterial conversion of ammonia to nitrite and nitrate. Nitrate can be used by plants and algae and is generally considered harmless to fish in natural waters (Zamzow, 2009). Ammonia's aquatic toxicity is principally due to the un-ionized form, as pH increases, the toxicity of ammonia increases because the relative proportion of unionized ammonia increases (Brinkman et al, 2009 and EPA, 1999).

Ammonia or NH_3, it is one of the most important pollutants in the aquatic environment because of its relatively highly toxic nature and its ubiquity in surface water systems. It is discharged in large quantities in industrial, municipal and agricultural waste waters that discharge to natural rivers. In aqueous solutions, ammonia assumes two chemical forms: NH_4^+ - ionized (less/nontoxic) and NH_3 - unionized (toxic). The relative concentration of ionized and unionized ammonia in a given ammonia solution are principally a function of pH, temperature and ionic strength of the aqueous solution, and Total NH_3: Total ammonia is the sum of the NH_3 and NH_4^+ (Rand and Petrocelli, 1985). The toxic form of ammonia ($NH3^0$) never exceeded the EPA recommendation for fish propagation, but a shift in pH from 7.5 to 8 with an increase of 1°C would cause some water to exceed ammonia criteria values (Zamzow, 2009).

7.8 Nitrogen as Nitrate

Nitrate plays an important role in the health of our fresh surface bodies and also our estuaries. Nitrogen is one of the key nutrients for the growth of aquatic plants, and thus an important link in the food chain. Nitrate or NO_3, Generally it occurs in trace quantities in surface water. It is the essential nutrient for many photosynthetic autotrophs and has been identified as the growth limit nutrient. It is only found in small amounts in fresh domestic wastewater, but in effluent of nitrifying biological treatment plants, nitrate may be found in concentrations of nitrate as nitrogen up to 30 mg/l (APHA, 1995). Nitrate is a less serious environmental problem, it can be found in relatively high concentrations where it is relatively nontoxic to aquatic organisms. However, when nitrate concentrations become excessive, and other essential nutrient factors are present, eutrophication and associated algal blooms can be become a problem (Rand and Petrocelli, 1985).

Nitrogen-containing compounds act as nutrients in streams and rivers. Nitrate reactions (NO3-) in fresh water can cause oxygen depletion. Thus, aquatic organisms depending on the supply of oxygen in the stream will die. The major routes of entry of nitrogen into bodies of water are municipal and industrial wastewater, septic tanks, feed lot discharges, animal wastes (including birds and fish) and discharges from car exhausts. Bacteria in water quickly convert nitrites (NO2-) to nitrates (NO3-).

7.9 Total Dissolved Solids (TDS)

Total dissolved solids, also known as TDS, come from a variety of places. Sometimes rock bits are dissolved into water, others come from run-off rain water, leaves, silt, or plankton. Chemicals from sewage treatment, pesticides, and road salts, and/or fertilizers, can also be dissolved in water, and contaminate both drinking supplies and bodies of water. Total dissolves solids (TDS) are naturally present in water or are the result of mining or some industrial treatment of water. TDS contain minerals and organic molecules that provide benefits such as nutrients or contaminants such as toxic metals and organic pollutants (Weber-Scannell and Duffy, 2007). Total dissolved solids cause toxicity through increases in salinity, changes in the ionic composition of the water and toxicity of individual ions. Increases in salinity have been shown to cause shifts in biotic communities, limit biodiversity, exclude less-tolerant species and cause acute or chronic effects at specific life stages. (Bierhuizen and Prepas, 1985).

On the other hand, the level of total dissolved solids in drinking water affects the taste of the water and higher levels of TDS can make water taste bitter, salty or brackish. However, levels of total dissolved solids affect animals much more than humans. In bodies of water, like rivers, higher levels of total dissolved solids often harm aquatic species. The TDS changes the mineral content of the water, which is important to survival of many animals. Also, dissolved salt can dehydrate the skin of aquatic animals, which can be fatal. It can increase then temperature of the water, which many animals can't survive in those places.

8. Surface Water Quality Standards of Thailand

Many parameters can influence the surface water quality. In Thailand, the surface water quality can be classified as showed in table 7. Generally, surface water quality can be divided into five classes; class I , extra clean fresh surface water resources use for conservation that are not necessary to pass through water treatment processes and require only ordinary processes for pathogenic destruction and ecosystem conservation where basic organisms can breed naturally; class II, very clean fresh surface water resources use for consumption that require ordinary water treatment processes before use by aquatic organisms in conservation, fisheries and recreation; class III, medium clean fresh surface water resources use for consumption, but are passed through an ordinary treatment process before use and it is suitable agricultural production; class IV, fairly clean fresh surface water resources use for consumption, but requires special water treatment processes before use; and class V, the sources which are not within class I to class IV and using navigation.

Table 7 Surface water quality standard in Thailand

Parameter	Unit	Class				
		I	II	III	IV	V
pH		<5	5 - 9	5-9	5-9	9>
DO	Mg/L	6>	6	4	2	<2
BOD	Mg/L	<1.5	1.5	2	4	>4
TCB	MPN/100ml	<5,000	5,000	20,000	>20,000	>20,000
FCB	MPN/100ml	<1,000	1,000	4,000	>4,000	>4,000
NO_3-N	Mg/L	<5	5	5	5	>5
NH_3-N	Mg/L	<0.5	0.5	0.5	0.5	0.5>
EC	µS/cm	N	N	N	N	N
TDS	Mg/L	N	N	N	N	N

Sources: Modified from PCD (2013)

9. Water Quality Management

In fact, there are many methods to protect surface water quality along the rivers, lacks and streams including wastewater treatment of industries, water use from household and communities before drain to natural rivers and control on the pesticide and chemical fertilizer utilizations from agricultural activities as well as surface water sources should be protected as much as possible from contamination by harmful pollutants. Surface water quality management could control water regulation, water utilization, wastewater sources by treatment before discharged to natural rivers (Costanza *et al.*, 1997). While water quality management by dilution of wastewater in rivers or streams by using natural water purification, soil erosion control, and management of forest protected areas could reduce harmful pollution in water (Loomis *et al.*, 2000). On the other hand, there are strong correlations between land use and water quality, and strong negative correlation between areas of urban land use and water quality degradation so that could manage as point sources (Kebede *et al*., 2003; Tong and Chen, 2002; Xian *et al*., 2007). If the areas of urban lands continue to expand, there will have to be more coordination between land use planning and water quality management to reduce the amount of pollution entering local water bodies. Land use planning and water quality management are typically managed separately with differing purposes. Land use planning often involves getting the most use from the land by humans in the future without negatively impacting humans' well being. On the other hand, water quality management is based on monitoring and enhancing water quality (Wang, 2001).

10. Point Sources of Polluted Water

There are different factors that contribute to surface water pollution, they are the most dangerous causes of water pollution such as industrial, Agricultural, human activities, household and natural factors.Many of the chemical substances are toxic, pathogens can produce waterborne diseases in either human or animal hosts (Hogan, 2010). However, the raw sewage, agriculture waste, urban garbage human and animal excrement and urine caused to dead organic matter pathogen; agriculture use of pesticides and herbicides produce organic chemicals and industrial processes produce dioxin; agriculture, urban and industrial use of mercury, lead, selenium and cadmium produce heavy metals; runoff from construction sites, agricultural runoff and natural erosion produce sediment; and warm to hot water from power plants and other industrial facilities produce heat (thermal pollution) and the contamination by nuclear power industry, military and natural sources cause to radioactivity (Botkin and Keller, 2005).

The major cause of artificial eutrophication, nitrates in groundwater and surface waters can cause pollution and damage to ecosystem and people, and heavy metals can cause significant ecosystem and human health problems, acids mine drainage is a major water pollution problem in many coal mining areas, damaging ecosystems and spoiling water resources. Agriculture use of pesticides and herbicides produce organic chemicals and industrial processes produce dioxin, which potential to cause significant ecological damage and human health problem (Botkin and Keller, 2005). NWA and NEMA (1998) stated that water quality is changed and affected by both natural processes and human activities. Generally natural water quality varies from place to place, depending on seasonal changes, climatic changes and with the types of soils, rocks and surfaces through which it moves. A variety of human activities e.g. agricultural activities, urban and industrial development, mining and recreation, potentially significantly alter the quality of natural waters, and changes the water use potential.

11. Effect of Water Pollution

The water pollution is very harmful to humans, animals and water life. The effects can be catastrophic, depending on the kind of chemicals, concentrations of the pollutants and where there are polluted (Siegel, 2007 and Eckenfelder, 2003). The contamination from road salt enters water resources by infiltration to groundwater, runoff to surface water and through storm drains. The accumulation and persistence of chloride poses a risk to the water quality and the plants, animals, and humans who depend upon it (Siegel, 2007). In addition to, the water contaminated with NaCl creates a higher water density and will settle at the deepest part of the water body where current velocities are low such as in ponds and lakes. This can lead to a chemical stratification which can impede turnover and mixing, preventing the dissolved oxygen within the upper layers of the water from reaching the bottom layers and nutrients within the bottom layers from reaching the top layers. This leads to the bottom layer of the water body becoming void of oxygen and unable to support aquatic life (Siegel, 2007 and Eckenfelder, 2003). The concentration of chloride found in surface water correlates with the proportion of impervious surfaces in the watershed. Chloride cannot be treated or filtered with some equipments, so once salt is applied, chloride remains in the watershed until it is flushed downstream. Given that groundwater residence time is so much longer, contaminated wells often must be replaced (Siegel, 2007).

However, the dissolved minerals may affect suitability of water for a range of industrial and domestic purposes. The most familiar of these is probably the presence of ions of calcium and magnesium which interfere with the cleaning action of soap, and can form hard sulphate and soft carbonate deposits in water heaters or boilers (Harold and James, 1949), and Ray and Joseph (1972) indicated that hard water may be softened to remove these ions. The softening process often substitutes sodium captions. Hard water may be preferable to soft water for human consumption, since health problems have been associated with excess sodium and with calcium and magnesium deficiencies. Softening decreases nutrition and may increase cleaning effectiveness (WHO, 2004).

MATERIALS AND METHODS

Materials

Materials and equipment for this study conduction, they were prepared before the real field survey of the study site and they were used during of the data collection in the field there are below:

1. Equipment for the water sample collection such plastic tank, it has size 1 liter, and grass bottle for keeping the water sampling.

2. Water quality measurement tools in the field such as dissolved oxygen meter, and conductivity meter.

3. Water quality measurement tools in the laboratory such as plates, Microwaves, turbidity meter, temperature, pH, DO, BOD, NO_3-N, NH_3-N, FCB, TDS, EC and TCB meter.

pH/temperature Plastic tank Grass bottle DO meter

Figure 13 Tools for water quality measurement

Methods

Determination on the water sampling point that could be representative of the community activities, which the first point was downstream area of the Phetchburi diversion dam, Thayang district to the Ban Lam of Ban Lam district in Phetchaburi province include 8 points along the Phetchaburi river. Due to the water quality was affected from the community activities such as households, agriculture, cage fish and fishery areas as well as non-point sources from Agricultural practices.

1. Water Quantity Measurement

In principles of fluid mechanics, the streamflow discharge (Q) is equivalent to multiply the cross-sectional area (A) by flow velocity of stream (V). The measured Q of the same stream is presumably equal to all measuring points in case of no inflow and no outflow, that is, A has to be inversely with V. In other words, the narrower stream causes the higher the flow velocity, in turn to make more and more momentum of stream discharge. The before statement is very necessary to understand in combining to dilution process that concerning with flow velocity and its quantity during in motion. So, Royal Irrigation Department has established the staff gages all the way of Phetchaburi river in order to obtain its discharge as well as its hydrograph that belonging to each sampling point (Linsley et al 1988 and Chunkao 2008). In case of non-available staff gage, the current meter can be used for getting flow velocity together with measuring cross-sectional area in which the discharge can be calculated from 12-year period between 2002 -2013 at that point on Phetchaburi riveras seen in Figure14.

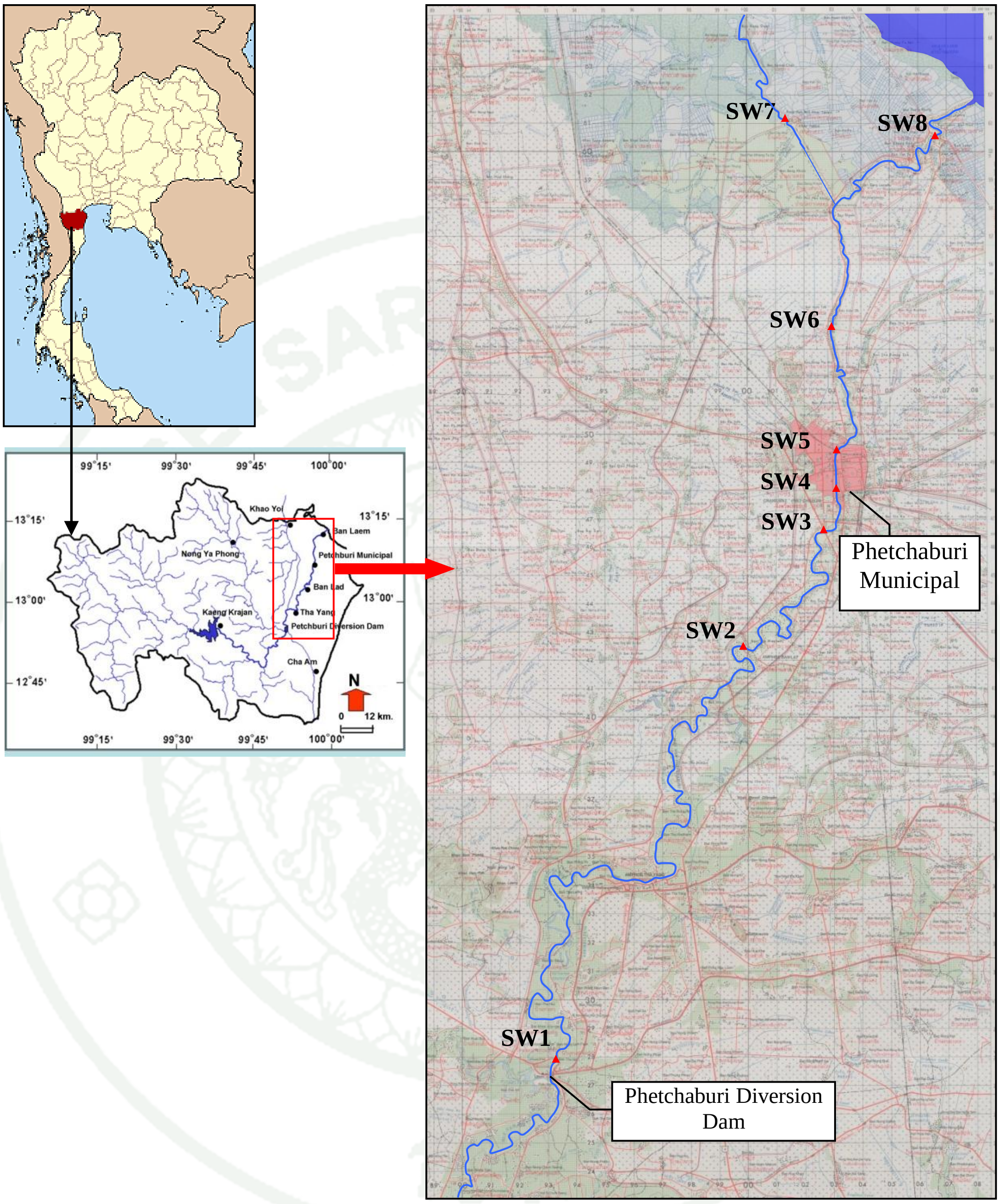


Figure 14 Locations of staff gages and water quality sampling points as established all the way from headwater to the outlet of Phetchaburi river.

Unexpectedly, there were few days of high intensity rainfall occurring over the headwater, Kaeng Krachan National Park and downstream areas during 7-11 November 2013 that caused surface water flowing above reservoir capacity.

Consequently, the Royal Irrigation Department had to drain out the excess stored water only along to Pethburi river, not to double-crop rice fields and Hua Hin district due to avoid the tangible and intangible losses. Because of excess water plus heavy rainfall, the occurrence of flood was spread over downstream all the way from the Phetchaburi diversion dam to watershed outlet at Ban Laem district, Phetchaburi province. Thus, Phetchaburi river was to support some toxic and non-toxic contaminants which were washed away from agricultural, villages, suburban, and urban areas by such overflowing water with the gravitational forces.

2. Localization of Sampling Points

Eight sampling points were purposively nlocalized on Phetchaburi river under three sections of land use and land cover for agricultural zone (SW1, SW2, and SW3), Municipal zone (SW3, SW4, SW5, and SW6) and fishery zone (SW6, SW7, and SW8) as illustrated in figure15. It was observed during field study that there were some amount of in-between-zone inflow from natural streamlets (creeks) to the agricultural zone (SW1-SW3) than the municipal zone (SW3-SW6) which mostly obtains inflow from municipal sewerage and also rainwater, but rather very small amount of inflow than outflow in fishery zone (SW6-SW8) in estuarine reach.

3. Water Quality Collection and Analyzing

Water samples were collected on each sampling point at 30-cm depth under the criteria of (APHA, 1992), (APHA.AWWA.WEF, 2005), (LERD, 1999, 2000, 2010, 2011, and 2012) and (Mathews and Richter, 2007) for analyzing mainly BOD and DO (and also another indicators such as COD, TSS, salinity, pH, etc. but using only for supporting factors in this research). Anyhow, the research is concentrated on normal, dry and wet flows in order to suit with the role in handling water for coping stream pollution dilution process for better water quality of Phetchaburi river from Phetchaburi diversion dam on the way to outlet at estuarine zone.

Phetchaburi diversion dam

Downstream of the Phetchaburi diversion dam (SW1)

Bridge of the Lad village (SW2)

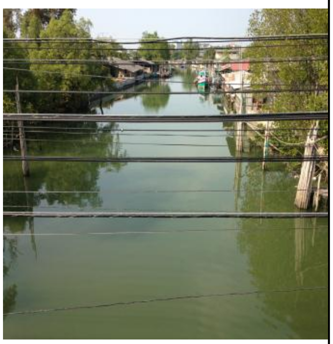
Bridge of Phetkasem road (SW3)

Bridge at the Chantravath temple (SW4)

Bridge at Phetchaburi municipality (SW5)

Bridge at Khountra temple (SW6)

Bridge at Khaotakao temple (SW7)



Bridge at Lam village (before water flow to the gulf of Thailand) SW8

Figure 15 Location of water sample location in Phetchaburi river.

RESULTS AND DISCUSSION

Results

Water quality parameters including water quantity in Phetchaburi river were measured every month for water quality monitoring in terms of physical and chemical indicators along the river particularly at eight sample water stations of the Phetchaburi river in the Phetchaburi province of Thailand. Addition to there has been water management at the Phetchaburi diversion dam for control and management of water resources for Agricultural areas and ecological conservation in downstream of Phetchaburi river as well as consumption of communities and tourist sites. This chapter, the first presents information on the sampling sites. Second, water management in the Phetchaburi watershed as well as water use demand for agricultural production, water consumption and water for maintaining environmental conservation. Then, variations in water quality at the different sampling locations and parameters over ten indicators and highlights of monthly water quality indicators in streamflow of Phetchaburi river as collected during 2002-2013 were presented. The last, correlations among water quality parameters and streamflow from Phetchaburi diversion dam for dilution of water quality and maintaining environmental and ecosystem conditions.

1. Sampling Site Description

The reason of the selection of the water sampling points/stations along the Phetchaburi river, the point 1 is downstream of the Phetchaburi diversion dam, which it is expected that water quality is quite clean because land use and other factors no change too much such as community activities, agricultural land and other point sources. The points 2-3 are in the agricultural land, which water sampling is a representative of the effect from the agricultural area. The points 4, 5 and 6 are in the density community’s location, which water sampling be able representative of the effect from the community activities, and last 2 points 7 and 8 are in the fisheries areas, which water sampling points are representative of the impact from fisheries before water was drained to the Gulf of Thailand. As showed in the table 8, the lists of the sites, all of the sites were in downstream of Phetchaburi diversion dam and water sampling location along with briefly site descriptions.

Table 8 Sampling site description

Site	Description	Distance (Km)
SW1	Downstream of the Phetchburi diversion dam	0
SW2	The bridge of the Lad village	30
SW3	The bridge of Phetkasem road, before water flow through the Phetchburi city	9
SW4	The bridge at the Chantravath temple, before water flow through the density community in along river bank	1.5
SW5	The bridge at municipality (near the office of district governor/ province governor)	1.8
SW6	The bridge at Khountra temple (after water flow through community area)	1.6
SW7	The bridge at Khaotakao temple (before water flow to Gulf of Bangtabun)	12.2
SW8	The bridge at Lam village (before water flow to the gulf of Thailand)	15.2

Source: Modified from LERD (2013)

2. Water Management in Upstream of Pechburi Diversion Dam

In fact, Phetchaburi watershed is divided three parts, the upstream watershed is in Kaeng krachan reservoir, middle part from downstream of Kaeng krachan reservoir to Phetchaburi diversion dam, and from Phetchaburi diversion dam to gulf of Thailand is downstream part of Phetchaburi river. So that the drainage was identified three ways and three main purposes of water use at Phetchaburi diversion dam. The first, it was drained from Phetchaburi diversion dam throughout downstream of Phetchaburi river to the gulf of Thailand at Bam Lam, Ban lam district for maintaining ecological and environmental condition. The second, it was drained to Irrigation systems for agricultural production around the Phetchaburi province. And the third, the water inflow to community's consumption around the Hua Hin district as well as study on the amount rainfall in Kaeng Krachan reservoir area.

2.1 Amount of rainfall at Kaeng Krachan reservoir station

As result of study on the amount of rainfall in Kaeng Krachan reservoir station in duration of study 2004 to 2013 found that amount of rainfall distributed in the Kaeng Krachan area, which rainfall was highest value in wet period, the average of the monthly rainfall was highest peak 232.4 mm/month in October, the next it was 183.9 mm/month in September, and it was 175.5 mm/month in May respectively as show in figure 16. But it was lowest in duration of dry period; it was lowest 9.0 mm/month in December, 11.9 mm/month in January and 13.5 mm/month in February respectively.

In fact, the amount of yearly rainfall in around the Kaeng Krachan reservoir area was 1,136.5 mm/year by average 10 years from 2004 to 2013 as showed in table 9. However, there was recording about average rainfall around Phetchaburi province of Meteorological Department (2009) illustrated that The Phetchaburi province is located the gulf of Thailand, therefore it is influenced by the southwest monsoon winds, and the rainfall data is recorded from 1982 to 2008 that average rainfall was 2,129.89 mm/year, average temperature was 28.02°C, average humidity was 75.98%, average evaporation rate was 108.60 mm/month, and average wind speed was 2.41 knots in the Phetchaburi province. Therefore, rainwater is main sources for water runoff to Kaeng krachan reservoir and be able main supporter to aquatic ecological situation along the Phetchaburi river and sustainable development of socio-economic of Phetchaburi province as well as Thailand.

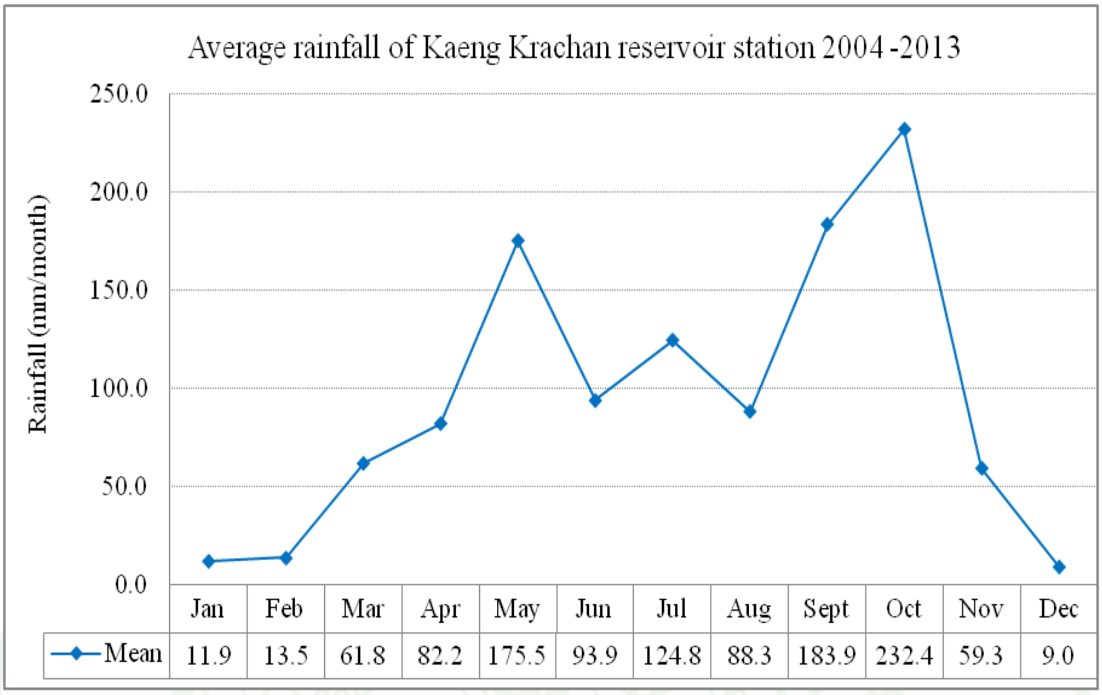


Figure 16 Amount of rainfall in Kaeng Kracha reservoir station 2004-2013

Source: Phetchaburi Irrigation Project (2013)

Table 9 Average of yearly rainfall in Kaeng Krachan reservoir area

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2002	40.18	59.61	63.05	77.76	76.87	77.76	84.24	164.16	234.99	184.01	78.17	32.38	1,173.18
2003	35.86	63.90	80.35	86.39	78.19	64.80	57.88	92.86	43.21	60.91	63.06	38.01	765.43
2004	27.21	78.20	88.13	107.57	69.13	103.24	176.27	173.67	124.86	53.57	77.35	31.95	1,111.13
2005	27.22	37.58	29.38	37.15	33.26	30.67	74.30	81.22	72.14	24.19	28.08	22.46	497.66
2006	37.15	60.48	90.72	85.54	79.92	66.10	261.49	300.11	283.20	173.49	91.15	27.22	1,556.57
2007	22.46	57.89	89.42	94.61	12.10	21.60	58.75	228.10	121.82	155.09	82.51	34.56	978.91
2008	34.56	74.74	98.06	94.18	89.86	58.75	50.98	124.42	84.24	65.23	18.67	31.97	825.65
2009	38.45	73.01	97.63	102.82	91.58	40.61	56.59	162.09	159.84	73.87	104.98	44.50	1,045.96
2010	28.51	72.14	121.82	123.55	114.05	67.39	31.97	78.19	54.86	2.38	60.05	36.72	791.64
2011	27.22	30.67	23.76	29.81	21.60	20.82	63.07	132.19	114.91	82.94	111.89	43.20	702.09
2012	43.20	99.79	112.75	109.30	66.96	315.36	47.95	117.50	106.27	97.37	70.85	16.85	1,204.16
2013	27.65	103.85	104.11	114.48	115.78								465.87
Mean	32.47	67.66	83.27	88.60	70.77	78.83	87.59	150.41	127.30	88.46	71.52	32.71	926.52

Source: Phetchaburi Irrigation Project (2013)

2.2 Water inflow to Kaeng Krachan reservoir

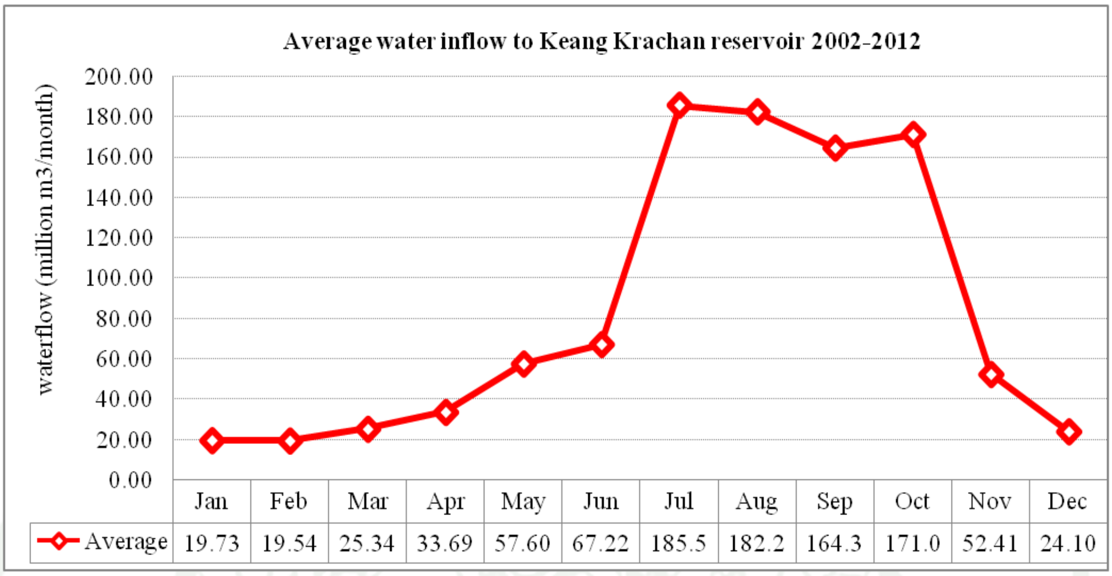


Figure 17 Average water inflow to Kaeng Krachan reservoir in each month 2002-13

Source: Phetchaburi Irrigation Project (2013)

Naturally, the Phetchaburi irrigation watershed (2,915 sq.km) has received the averaged annual rainfall input approximately 1,750 mm by isohyetal and facet methods (Linsley et al 1988 and Chunkao 2008), minimum 944.7 mm in downstream areas (from Kaeng Krachan reservoir) and maximum 2,335.0 mm to the highest point at 1,202 m MSL, which is equivalent to rainwater about 5,930 MCM per annum. In forested headwater (1,545 sq.km) as located inside Kaeng Krachan National Park, the averaged annual rainfall input was determined about 2,230 mm, then converting into rainwater approximately 7,480 MCM per annum. Therefore, the Kaeng Krachan reservoir is a main water storage source of Phetchaburi watershed area, which it has highest water storage level 103.56 m and maximum capacity 900 MCM, normal water storage level be 99.00 m and water quantity 710 MCM, lowest water storage level be 75.00 m and water quantity 65 MCM. The water inflow to Kaeng Krachan reservoir in each month by average in 2002-2012 as showed in figure 17, it was highest 185.5 MCM/month in July and 182.2 MCM/month in August, water inflow was lowest 19.73 MCM/month in January and it was slightly increased 19.54; 25.34; 33.69 and 57.60 MCM/month in February to May respectively. However, wet period had water inflow to Kaeng Krachan reservoir more in dry season period.

On the other hand, the water inflow to Kaeng Krachan reservoir about 1,002.92 MCM/year by average in duration of study 2002-2012, which it was 223.12 MCM/year in dry season period (23.65%) of total water inflow and 779.80 MCM/year in wet season period (76.35%) of total water inflow, which detail it was showed in table 10. The water inflow to Kaeng Krachan is a significant factor for balance water storage of reservoir condition and also to be headwater sources for maintaining ecosystem and environmental condition in downstream of Phetchaburi river.

Table 10 Water inflow to Kaeng Krachan reservoir 2002-2012

Year	Dry Season		Wet Season		Total flow
	MCM	% Dry flow	MCM	% Wet flow	(MCM)
2002	240.1	18.84	1,034.60	81.16	1,274.70
2003	175.3	15.42	961.49	84.58	1,136.79
2004	302.55	40.41	446.12	59.59	748.67
2005	93.82	11.68	709.24	88.32	803.06
2006	245.42	16.48	1,243.70	83.52	1,489.12
2007	170.27	16.02	892.43	83.98	1,062.70
2008	206.27	26.91	560.16	73.09	766.43
2009	350.41	28.33	886.57	71.67	1,236.98
2010	192.88	36.92	329.57	63.08	522.45
2011	204.49	17.08	993.08	82.92	1,197.57
2012	289.82	27.20	775.63	72.80	1,065.45
Average	223.12	23.65	779.80	76.35	1,002.92

Source: Phetchaburi Irrigation Project (2013)

2.3 Water outflow from Kaeng Krachan reservoir

As a result of study on the water release from Kaeng Krachan reservoir in each month of study duration 2002 to 2013 found that the water discharge was highest peak 150.4 MCM/month in August of wet season before it was slightly reduced 127.3 MCM/month, 88.46 MCM/month, 71.52 MCM/month and 32.71 MCM/month from September to December respectively, and it was lowest 32.47 MCM/month in January of dry season and it was slowly increased 67.66 MCM/month; 83.27 MCM/month; 88.60 MCM/month in February, March and April respectively before decreased to 70.77 MCM/month in May, detail of water outflow trend was showed in figure 18. Which water outflow from Kaeng Krachan has influenced to water use in the downstream of communities and maintaining ecosystem and environmental condition particularly aquatic ecosystem of Phetchaburi river as well as dilution of water quality and push brackish water around river mouth in gulf of Thailand.

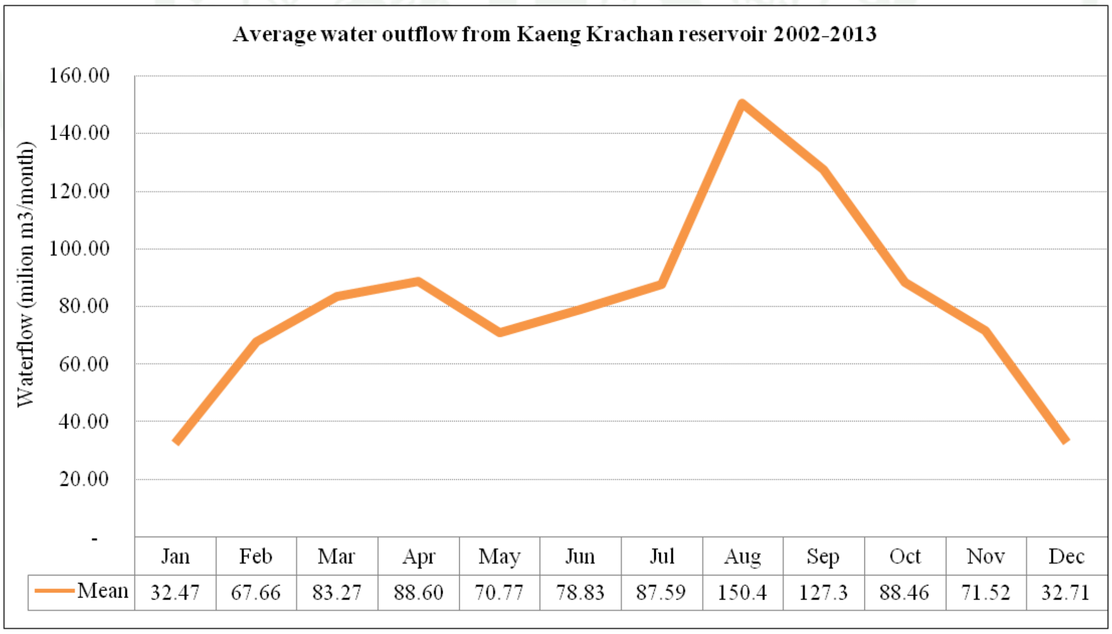


Figure 18 Average water outflow from Kaeng Krachan reservoir 2002-2013

Source: Phetchaburi Irrigation Project (2013)

In addition to, the water drainage from Kaeng Krachan reservoir to Phetchaburi river, it averaged 926.52 MCM/year over study 2002-2013, and it 415.02 MCM/year equal (43.10%) in dry season period and 557.99 MCM/year (56.90%) in wet season period as showed in table 11. In fact, the water quantity inflow and outflow has been balanced in dry and wet season period in the Kaeng Krachan reservoir due to it has been Natural Park and conservation areas so that it has been well managed and has organization units respond to this area for maintaining and conservation biodiversity in terms of terrestrial and aquatic ecosystem.

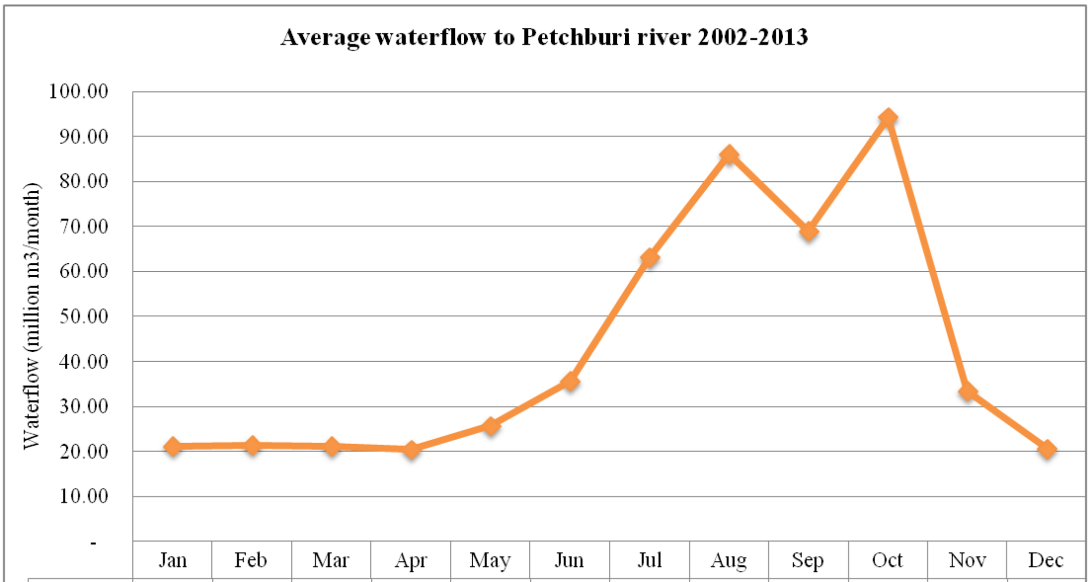
Table 11 Average of water outflow from Kaeng Krachan reservoir 2002-2013

Year	Dry Season		Wet Season		Total flow
	MCM	% Dry flow	MCM	% Wet flow	(MCM)
2002	395.22	33.69	777.95	66.31	1,173.17
2003	409.51	53.50	355.93	46.50	765.44
2004	473.48	42.61	637.66	57.39	1,111.14
2005	195.26	39.24	302.4	60.76	497.66
2006	419.9	26.98	1,136.66	73.02	1,556.56
2007	298.08	30.45	680.83	69.55	978.91
2008	450.14	54.52	375.5	45.48	825.64
2009	444.1	42.46	601.86	57.54	1,045.96
2010	527.47	66.63	264.17	33.37	791.64
2011	153.88	21.92	548.21	78.08	702.09
2012	747.36	62.07	456.77	37.93	1,204.13
2013	465.88				465.88
Average	415.02	43.10	557.99	56.90	926.52

Source: Phetchaburi Irrigation Project (2013)

2.4 Water flow quantity for maintaining ecosystem in Phetchaburi river

In general, the stream pollution of Phetchaburi river is usually occurred in both situations, very dry period and too much needs of water for growing rice. Aforesaid statement could be induced to handle water flow from Phetchaburi diversion dam to use for reduce the stream pollution condition through the dilution process. In other words, handling water from Phetchaburi diversion dam can be stressed as a key issue on water quality management Phetchaburi river for serving needs of people who lives along the riverbanks and remote communities as well as cultivated areas. The details of study will be presented in the following sections. As showed in figure 19, the water discharge from Phetchaburi diversion dam to downstream of Phetchaburi river for the maintaining ecosystem and environmental conservation, the average of water drainage to Phetchaburi river downstream in during study 2002-2013, it was highest peak 94.32 MCM/month in October, next 86.09 MCM/month in August and 68.97 MCM/month in September. It was lowest 20.45 MCM/month in April, which water drainage to Phetchaburi river was different in each month especially in dry season and wet season period. Addition to, it averaged 502.53 MCM/year for maintaining ecosystem and environmental conservation, in the same time, water drainage to downstream 142.07 MCM/year equivalent (31.20%) in dry season period and 359.89 MCM/year equivalent (68.80%) in wet season period as showed in table 12. In case of heavy rain, the water manager has to drain excessive inflow more than drying periods approximately 4 times such condition showing during 2002-2013



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	21.18	21.40	21.17	20.45	25.69	35.62	63.13	86.09	68.97	94.32	33.41	20.57

Figure 19 Average of water inflow to downstream of Phetchaburi river 2002 to 2013

Table 12 Average of water inflow to downstream of Phetchaburi river 2002 to 2013

Year	Dry Season		Wet Season		Total flow
	MCM	% Dry flow	MCM	% Wet flow	(MCM)
2002	148.95	24.01	471.47	75.99	620.42
2003	127.02	29.67	301.02	70.33	428.04
2004	244.27	37.02	415.62	62.98	659.89
2005	111.04	29.68	263.13	70.32	374.17
2006	167.76	16.47	850.61	83.53	1018.37
2007	141.25	20.47	548.76	79.53	690.01
2008	107.85	41.61	151.35	58.39	259.2
2009	77.76	19.56	319.76	80.44	397.52
2010	172.16	44.99	210.54	55.01	382.7
2011	136.83	33.82	267.74	66.18	404.57
2012	146.22	38.72	231.41	61.28	377.63
2013	130.57	31.25	287.28	68.75	417.85
Average	142.07	31.21	359.89	68.79	502.53

Source: Phetchaburi Irrigation Project (2013)

2.5 Water consumption for Hua Hin district

Regarding to the water management in upstream of Phetchaburi diversion dam for water consumption of people in the communities of Hua Hin district, which water flow to natural canal to the Hua Hin district. In general, the average water flow was highest 19.63 MCM/month in August of during study 2002-2013 and it was lowest 3.18 MCM/month on December of wet season period, which it was highest 13.443 MCM/month on April and to be lowest 1.42 MCM/month on January of dry season period, detail of average monthly water flow trend as showed in figure 20. On the other word, average water flow for community consumption in Hua Hin district, it averaged 137.51 MCM/year over the study in 2002 to 2013. In dry season period, it was 53.88 MCM/year and equal (37.84 %) of total water flow, and it drained 83.63 MCM/year and equal (62.16%) of total drainage as showed in table 13. However, water flow to people consumption in Hua Hin district, it is a significant issue due to almost of people who have been living in this district, and they have been utilized main water sources from Petchuburi river for consumption in household and industry use on daily life.

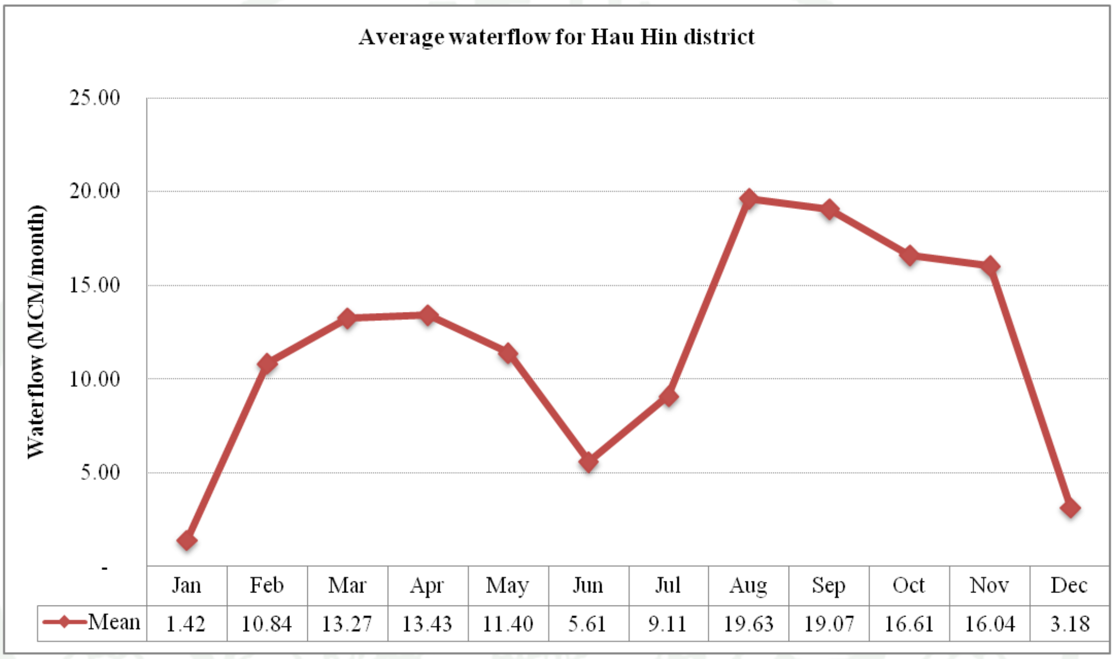


Figure 20 Average monthly water flow to Hua Hin district 2002-2013.

Table 13 Average of water consumption for Hua Hin district 2002-2013

Year	Dry Season		Wet Season		Total flow
	MCM	% Dry flow	MCM	% Wet flow	(MCM)
2002	37.86	26.25	106.35	73.75	144.21
2003	28.65	27.47	75.64	72.53	104.29
2004	73.56	44.54	91.59	55.46	165.15
2005	22.25	22.59	76.26	77.41	98.51
2006	66.52	30.92	148.62	69.08	215.14
2007	53.01	31.47	115.43	68.53	168.44
2008	91.23	54.11	77.36	45.89	168.59
2009	58.76	40.55	86.13	59.45	144.89
2010	48.39	51.33	45.89	48.67	94.28
2011	15.55	23.24	51.35	76.76	66.90
2012	79.59	63.73	45.3	36.27	124.89
2013	71.2				71.20
Average	53.88	37.84	83.63	62.16	137.51

Source: Phetchaburi Irrigation Project (2013)

2.6 Water use for agricultural production.

According to result of study and analysis on the water use for agricultural production, in fact, there are three main canals of irrigation systems that supplying water to irrigated areas and there are total irrigated areas about 74,925 hectares. The average of water use for agricultural production was highest 73.25 MCM/month in July before be slightly decreased 70.50; 64.67; 61.55 and 57.76 MCM/month in August, September, October, November respectively then it was became to be lowest 19.68 MCM/month in December of during wet season period. In dry season, it was started 20.78 MCM/month in January and increased 62.62 MCM/month in April as showed in figure 21. In addition to, the annual average of water use for agricultural production was 596.22 MCM/year, in dry season period it was 275.64 MCM/year or equal (45.31%) of total water use for agricultural production, and in wet season period, it was 320.58 MCM/year or equal (54.69%) of total water flow for irrigation system as illustrated in table 14. However, the main purpose of water use has been provided to agricultural production areas particularly in dry season period, so that water managers at Phetchaburi diversion dam has been focused on main irrigated areas.

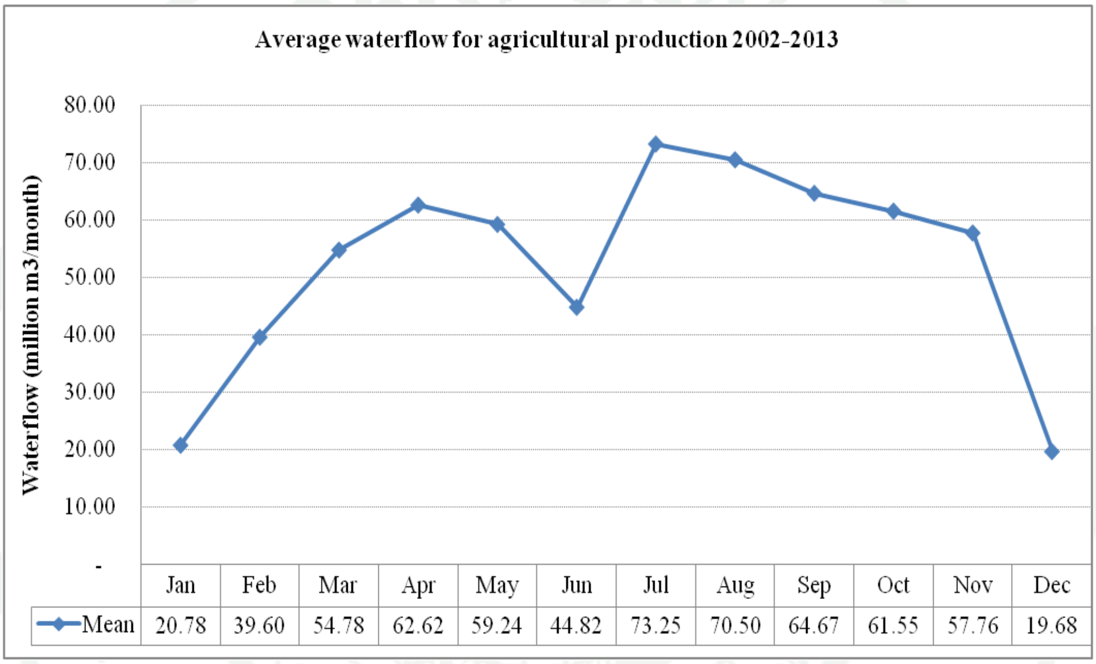


Figure 21 Water flow for agricultural production 2002-2013

Table 14 Water flow quantity for agricultural production 2002-2013

Year	Dry Season		Wet Season		Total flow
	MCM	% Dry flow	MCM	% Wet flow	(MCM)
2002	257.85	40.98	371.32	59.02	629.17
2003	299.4	48.72	315.09	51.28	614.49
2004	317.79	48.45	338.15	51.55	655.94
2005	156.35	35.47	284.43	64.53	440.78
2006	330.56	44.25	416.55	55.75	747.11
2007	248.79	43.84	318.75	56.16	567.54
2008	350.69	54.26	295.67	45.74	646.36
2009	292.65	45.49	350.67	54.51	643.32
2010	376.43	59.04	261.16	40.96	637.59
2011	107.54	26.27	301.85	73.73	409.39
2012	290.95	51.62	272.73	48.38	563.68
2013	278.73				278.73
Average	275.64	45.31	320.58	54.69	596.22

Source: Phetchaburi Irrigation Project (2013)

However, water management at the Phetchaburi diversion dam has been devised three purposes including agricultural production, maintaining ecosystem and consumption of Hua Hin district. For agricultural production was 277.26 MCM/year (58.41%) of total water flow in dry season period, the maintaining ecosystem of downstream of Phetchaburi river was 142.07 MCM/year (29.93%) and people's consumption in Hua Hin district was 55.34 MCM/year (11.66%) of total water use in dry season over study 2002-2013. In wet season, the agricultural production was 315.51 MCM/year (41.91%) of total water use in wet season, for downstream of Phetchaburi river was 355.99 MCM/year (47.29%) and for Hua Hin district was 81.36 MCM/year (10.81%). So that water management has influenced to water quality in downstream of Phetchaburi river, on the other hand, the stream pollution of Phetchaburi river is usually occurred in both situations, very dry period and too much needs of water for growing rice. Aforesaid statement could be induced to handle water flow from Phetchaburi diversion dam to use for reduce the stream pollution condition through the dilution process. In other words, handling water from Phetchaburi diversion dam can be stressed as a key issue on water quality management Phetchaburi river for serving needs of people who lives along the riverbanks and remote communities as well as cultivated areas. Addition to, normal water flow to downstream of Phetchaburi river was only 10 m^3/s in dry period and about 23 m^3/s in wet period of during of investigation 2002-2013. Water flow for Hua Hin tourist city about 4 m^3/s and 5 m^3/s in dry and wet period respectively, and for agricultural production about 18 m^3/s and 20 m^3/s in dry and wet period respectively.

Table 15 Average of water use demand in the Phetchaburi river

No	Water use demand	Water use percentage	
		MCM/year	Volume (%)
1	Consumption and tourism	19.12	1.43
2	Agriculture	1,152.54	85.98
3	Industrial	6.1	0.46
4	Livestock	5.03	0.38
5	Maintaining ecosystem in downstream of streams	157.68	11.76
	Total	1,340.47	100

Source: Modified from HAII (2013)

On the other hand, there was report on the water use in along with Phetchaburi river, the main sector is Agricultural production in dry season and wet season by under management of Phetchaburi Irrigation Project, in addition to, there are industrial, people consumption, tourism, livestock, and water use for ecological conservation in downstream of Phetchaburi river. Details of water use demand as showed in table 15. Which agricultural production water demand was 85.98% of all sectors that need to water use on Phetchaburi river, and also the maintaining ecosystem in downstream of Phetchaburi river was 17.76%, for consumption and tourism was 1.43%, 0.46% and 0.38% for industrial and livestock sectors respectively.

3. Water Quality Characteristic in Phetchaburi River

The research team of Royal LERD project office has collected monthly water samples for analyzing water quality indicators of streamflow in Phetchaburi river since 1995 after starting up the project 5 years in order to monitor the employment of oxidation pond and constructed wetland technologies for community wastewater treatment. The previous results have been somewhat satisfied to every water quality indicator but there were a big-worse problem for short period of time due to more amount of solid and dissolve organic substances as well as concerned indicators. However, the analyzed water quality indicators were illustrated on the highlight of water quality indicators in extreme dry year 2009, heavy rain year 2010 and coldest year 2011 in duration of study which indicated the condition of existing indicators.

3.1 Water temperature

As a result of monitoring and study on the water temperature found that lowest water temperature ranged 25.8-28.3°C at WS1 in dry period and highest ranged 27.2-33.7˚C at SW8 of extreme dry year 2009, it was lowest range 24.9-30.0˚C and highest 25.7-32.7˚C at SW8 in wet period of extreme dry year 2009. In heavy rain year 2010, it was lowest range 26.9-29.2˚C and highest 26.7-31.7˚C at SW1 and SW8 respectively in dry period, it was lowest range 27.8-30.9˚C and highest 2.7.4-33.0˚C at WS1 and SW8 respectively in wet period. In coldest year 2011, it was lowest range 26.6-30.2˚C and highest 26.5-32.1˚C at SW3 and SW8 respectively in dry period, it was lowest range 27.8-31.1˚C and highest 27.4-33.0˚C at WS1 and SW8 respectively in wet period. Water temperature is a significant indicator and influence to other indicators of water quality in terms of physical, chemical parameters, which details of water temperature indicators that it trended as distance and velocity of water flow, it showed in table 16

Table 16 Water temperature (°C) highlight of monthly water quality indicators in streamflow of Phetchaburi river as collected during 2006-2013.

Station	Extreme dry year 2009		Heavy rain year 2010		Coldest years 2011	
	Dry	Wet	Dry	Wet	Dry	Wet
SW1	25.8-28.3	25.4-30.0	26.9-29.2	27.8-30.9	26.6-30.3	27.8-31
SW2	27.4-31.7	24.9-30.0	26.9-30.2	28.2-31.5	27.1-30.3	27.5-32
SW3	28.5-32.5	25.5-32.5	27.3-30.3	28.7-31.7	26.6-30.2	27.4-32
SW4	28.5-34.1	26.0-30.5	27.5-30.7	28.6-31.9	26.9-30.6	27.4-32
SW5	28.4-33.0	26.4-31.0	27.7-31.1	28.8-32.2	27.0-31.2	27.7-32
SW6	28.8-32.5	26.4-31.3	27.6-31.0	28.6-32.3	27.0-31.0	27.5-32
SW7	28.3-32.9	25.7-31.7	27.5-31.5	29.0-32.5	27.4-31.6	27.3-32
SW8	27.2-33.7	25.7-32.7	26.7-31.7	27.4-33.0	26.5-32.1	27.4-33

Note: - Extreme dry Years, Heavy Rainfall Years and Coldest Years were base on statistic of Phetchaburi Meteorological Station between 2005 to 2013
- Dry Period is December-April and Wet Period is May-November
- SW1-SW3 is agricultural zone, SW4-SW6 is municipal zone and SW7-SW8 is estuarine zone

3.2 pH

The monitoring and study on the pH found that the all of study on pH concentration in the during 2006 to 2013 particularly in extreme dry year 2009, heavy rain year 2010 and coldest year 2011, in general, pH concentration of Phetchaburi river was under standard of pH as it was determined in the surface water quality standard (pH = 5-9) of pollution control department of Thailand, and it considered in class 3 of natural river, which mean that water quality is a medium clean fresh surface water resources, and can use for consumption but it should be passed through an ordinary treatment processes before use it and also it could be applied for Agricultural sectors, and detail of change of pH showed in table 17.

Table 17 pH highlight of monthly water quality indicators in streamflow of Phetchaburi river as collected during 2006-2013.

Station	Extreme dry year 2009		Heavy rain year 2010		Coldest years 2011	
	Dry	Wet	Dry	Wet	Dry	Wet
SW1	7.7-8.1	7.5-8.2	6.8-7.8	6.8-8.0	6.8-8.1	7.2-8.0
SW2	7.3-7.9	6.6-8.1	6.3-7.5	6.7-8.0	6.8-7.5	7.1-7.5
SW3	7.6-7.9	6.7-7.7	6.9-7.6	6.7-8.0	6.8-7.5	6.9-7.5
SW4	7.4-8.2	6.7-7.6	6.9-7.6	6.8-7.9	6.9-7.7	6.8-7.6
SW5	7.6-8.3	6.3-7.6	6.9-7.5	7.0-7.8	6.9-7.9	7.0-8.3
SW6	7.9-8.4	6.6-7.7	7.2-8.0	7.0-8.3	7.1-8.0	7.0-8.4
SW7	6.9-7.5	6.4-7.3	6.5-7.1	6.9-7.4	7.1-7.5	7.0-7.4
SW8	6.4-7.4	6.4-7.1	6.7-6.9	6.9-7.2	7.1-7.5	7.0-7.4

Note: - Extreme dry Years, Heavy Rainfall Years and Coldest Years were base on statistic of Phetchaburi Meteorological Station between 2005 to 2013

- Dry Period is December-April and Wet Period is May-November
- SW1-SW3 is agricultural zone, SW4-SW6 is municipal zone and SW7-SW8 is estuarine zone

3.3 Dissolved Oxygen (DO)

Dissolved oxygen concentrations at the eight sampling sites, it is showed table 18. In general, the dissolved oxygen concentration in beginning point was quite better than last point (SW1 and SW8) respectively. In dry period, which DO ranged 6.5-8.7 mg/L at SW1 and ranged 3.3- 4.8 mg/L at SW8 of extreme dry year 2009, it was highest 7.7-8.8 mg/L at SW6 in the Municipal areas. In wet period, DO ranged 6.2-8.1 mg/L and 3.2-4.9 mg/L at SW1 and SW8 respectively, and it was highest 5,7-8.9 mg/L at SW6. In heavy rain year 2010, DO ranged 6.2-8.2 mg/L and 3.7-4.1 mg/L at SW1 and SW8 respectively in dry period, and DO ranged 4.7-7.5 mg/L and 2.4-5.2 mg/L at SW1 and SW8 respectively in wet period. In coldest year 2011, DO ranged 5.4-6.9 mg/L and 2.8-4.3 mg/L at SW1 and SW8 respectively in dry period, and it ranged 3.0-7.0 mg/L and 1.2-5.0 mg/L at SW1 and SW8 respectively in wet period. However, the majority of DO value was lowest in dry season and highest in wet season because water inflow from Phetchaburi diversion dam to downstream of Phetchaburi river was less than in wet season, which were causes of problem on water quality in downstream of Phetchaburi river.

Table 18 DO (mg/L) highlight of monthly water quality indicators in streamflow of Phetchaburi river as collected during 2006-2013.

Station	Extreme dry year 2009		Heavy rain year 2010		Coldest years 2011	
	Dry	Wet	Dry	Wet	Dry	Wet
SW1	6.5-8.7	6.2-8.1	6.2-8.2	4.7-7.5	5.4-6.9	3.0-7.0
SW2	5.6-7.2	5.2-6.7	5.9-6.7	4.1-6.5	4.8-6.3	3.0-5.8
SW3	5.1-7.3	5.3-6.9	5.7-7.1	4.2-7.2	5.0-6.3	2.9-6.3
SW4	5.9-8.4	5.6-7.9	6.9-7.6	4.5-7.8	5.4-6.9	3.3-6.3
SW5	6.9-9.2	5.9-8.8	6.9-8.2	4.8-8.5	4.8-7.8	3.2-6.5
SW6	7.7-8.8	5.7-8.9	6.3-7.7	4.3-8.3	5.4-8.7	3.1-6.5
SW7	3.3-7.0	4.1-5.5	3.8-5.2	3.5-4.8	3.6-5.6	2.5-5.6
SW8	3.3-4.8	3.2-4.9	3.7-4.1	2.4-5.2	2.8-4.3	1.2-5.0

Note: - Extreme dry Years, Heavy Rainfall Years and Coldest Years were base on statistic of Phetchaburi Meteorological Station between 2005 to 2013
- Dry Period is December-April and Wet Period is May-November
- SW1-SW3 is agricultural zone, SW4-SW6 is municipal zone and SW7-SW8 is estuarine zone

Addition to, result of study found that, in general, the temporal variation of dissolve oxygen concentration not much different in each year from 2006 to 2013. So that it compared with water quality at SW8 was poorer than at SW1 due to it is effected from many factors during the water way from SW1 to SW8, and if comparing DO values with surface water quality standard of pollution control department of Thailand, it considered in class 3 of natural river, which mean that water quality is a medium clean fresh surface water resources, and can use for consumption but it should be passed through an ordinary treatment processes before use it and also it could be applied for Agricultural sectors.

3.4 Biochemical Oxygen Demand (BOD)

The concentration of biological oxygen demand in Phetchaburi river showed in table 19. In extreme dry year 2009, BOD concentration was lowest range 1.0-2.5 mg/L and highest range 3.4-5.6 mg/L at SW4 and SW8 respectively in dry period, and it was lowest range 1.2-2.5 mg/L and highest 2.9-4.8 mg/L at SW4 and SW8 respectively in wet period. In heavy rain year 2001, BOD was lowest range 1.5-6.8 mg/L and highest 2.0-5.0 mg/L at SW1 and SW8 respectively in dry period, and it was lowest range 1.0-6.2 mg/L and highest 2.4-8.6 mg/L at SW6 and SW8 respectively in wet period. In coldest year 2011, BOD was lowest range 1.1-4.4 mg/L and highest 2.7-7.7 mg/L at SW4 and SW7 respectively in dry period, and it was lowest range 0.4-3.2 mg/L and highest 1.5-7.2 mg/L at SW2 and SW8 respectivelyin wet period. Addition to, the change of biochemical oxygen demand concentration slowly increased from SW1 to SW2 in agricultural area before through municipal areas SW3 to SW6, it slightly decreased then it slowly increased in SW7 and SW8 in fishery areas before streamflow to Gulf of Thailand. If the comparing BOD values with surface water quality standard of pollution control department of Thailand, it considered in class 3 of natural river, which mean that water quality is a medium clean fresh surface water resources, and can use for consumption but it should be passed through an ordinary treatment. On the other hand, the BOD concentration level slowly increased as distance/spatial of streamflow.

Table 19 BOD (mg/L) highlight of monthly water quality indicators in streamflow of Phetchaburi river as collected during 2006-2013.

Station	Extreme dry year 2009		Heavy rain year 2010		Coldest years 2011	
	Dry	Wet	Dry	Wet	Dry	Wet
SW1	1.7-4.0	1.2-2.8	1.5-6.8	1.4-7.6	1.2-2.3	1.0-4.1
SW2	1.8-3.1	1.0-3.1	1.4-7.6	1.8-4.8	1.3-3.6	0.4-3.2
SW3	1.6-3.5	1.1-3.6	1.4-7.7	1.9-5.7	1.3-2.3	1.1-3.2
SW4	1.0-2.5	1.2-2.5	1.4-7.1	1.3-6.4	1.1-4.4	1.1-3.2
SW5	1.2-4.0	1.3-3.3	1.8-8.0	1.2-8.3	1.3-3.1	1.4-4.2
SW6	1.1-4.7	1.8-2.6	1.8-7.0	1.0-6.2	1.4-2.9	1.1-4.3
SW7	2.8-3.3	2.8-4.0	1.7-5.0	2.1-8.4	2.7-7.7	0.6-4.5
SW8	3.4-5.6	2.9-4.8	2.0-5.0	2.4-8.6	1.2-8.9	1.5-7.2

Note: - Extreme dry Years, Heavy Rainfall Years and Coldest Years were base on statistic of Phetchaburi Meteorological Station between 2005 to 2013

- Dry Period is December-April and Wet Period is May-November
- SW1-SW3 is agricultural zone, SW4-SW6 is municipal zone and SW7-SW8 is estuarine zone

3.5 Total Dissolved Solids (TDS)

In general, the highlights of the TDS concentrations, it was taken only extreme dry year 2009, heavy rain year 2010, and coldest year 2011, in fact TDS concentration was quite well water quality in beginning point of water sampling (SW1), which it ranged 56-85 mg/L at SW1 and slowly increased 3,840-23,229 mg/L at SW7 and 5,080-34,452 mg/L at SW8 in dry period of extreme dry year 2009, and it ranged 46-132 mg/L at SW1 and increased 104-4,016 mg/L to 236-15,928 mg/L at SW7 and SW8 respectively in wet period of extreme dry year 2009. In heavy rain year 2010, TDS was lowest range 68-178 mg/L and highest 5,968-28,080 mg/L at SW1 and SW8 respectively in dry period, it was lowest in SW1 and highest in SW8 in wet period. In coldest year 2011, TDS concentration was lowest and highest in SW1 and SW8 respectively in both dry and wet periods. However, the TDS value did not identify in the surface water quality standard of pollution control department of Thailand, but it rapidly tended from SW6 to SW7 and SW8, because it is influenced of brackish water that came from gulf of Thailand at Ban Lam area as showed in table 20.

Table 20 TDS (mg/L) highlight of monthly water quality indicators in streamflow of Phetchaburi river as collected during 2006-2013.

Station	Extreme dry year 2009		Heavy rain year 2010		Coldest years 2011	
	Dry period	Wet period	Dry period	Wet period	Dry period	Wet period
SW1	56-85	46-132	68-178	68-150	84-104	53-142
SW2	61-108	51-108	80-166	73-153	90-121	59-143
SW3	64-122	55-111	80-166	72-155	96-129	61-145
SW4	66-124	52-114	80-166	72-157	98-135	61-144
SW5	66-124	52-118	82-162	73-158	100-141	62-146
SW6	68-131	51-121	83-162	74-156	103-146	62-146
SW7	3,840-23,229	104-4,016	7,272-17,040	240-6,424	3,112-19,520	118-2,800
SW8	5,080-34,452	236-15,928	5,968-28,080	296-17,040	4,744-24,800	150-9,712

Note: - Extreme dry Years, Heavy Rainfall Years and Coldest Years were base on statistic of Phetchaburi Meteorological Station between 2005 to 2013

- Dry Period is December-April and Wet Period is May-November
- SW1-SW3 is agricultural zone, SW4-SW6 is municipal zone and SW7-SW8 is estuarine zone

3.6 Electrical conductivity (EC)

Electrical conductivity refers to the ability of a substance to conduct an electrical current. The result of water quality indicator analysis of the electrical conductivity indicated where high levels of dissolved and suspended solids are introduced to the stream, in general, electrical conductivity levels tend to increased from SW1 to SW8 as distance of the Phetchaburi river. The significant changes in electric conductivity can be used as an indicator of potential impacts in the Phetchaburi river, the result of study found that EC value was lowest range 113-128 (µS/cm) and highest 10,240-39,600 (µS/cm) at SW1 and SW8 respectively in dry period of extreme dry year 2009, and it was lowest range 81-122 (µS/cm) and highest 354-17,140 (µS/cm) at SW1 and SW8 in wet period of extreme dry year 2009. In heavy rain year 2010, it was lowest range 102-266 (µS/cm) and highest 7,460-35,100 (µS/cm) at SW1 and SW8 respectively in dry period, and in wet period, EC was lowest range 102-277 and highest 444-21,300 at SW1 and SW8 respectively. In coldest year 2011, it was lowest range 79-194 (µS/cm) and highest 3,890-24,400 (µS/cm) at SW3 and SW7 respectively in dry period, and lowest range 80-271 and highest 227-25,600 (µS/cm) at SW1 and SW8 respectively in wet period. However, electric conductivity values it little changed between SW1 to SW6 and it dramatically tended in SW7 and SW8, details of change of EC as showed in table 21.

Table 21 EC (µS/cm.) highlight of monthly water quality indicators in streamflow of Phetchaburi river as collected during 2006-2013.

Station	Extreme dry year 2009		Heavy rain year 2010		Coldest years 2011	
	Dry period	Wet period	Dry period	Wet period	Dry period	Wet period
SW1	113-128	81-122	102-266	102-277	128-159	80-271
SW2	121-145	76-163	120-248	109-229	136-185	89-219
SW3	129-182	76-167	121-249	108-233	79-194	92-221
SW4	122-188	78-172	120-248	109-236	148-203	93-220
SW5	122-187	78-178	122-244	110-237	153-210	94-223
SW6	125-195	77-195	124-244	111-234	156-219	98-223
SW7	2,820-27,200	157-5,020	9,090-21,300	360-11,370	3,890-24,400	179-3,500
SW8	10,240-39,600	354-17,140	7,460-35,100	444-21,300	5,930-18,250	227-25,600

Note: - Extreme dry Years, Heavy Rainfall Years and Coldest Years were base on statistic of Phetchaburi Meteorological Station between 2005 to 2013

- Dry Period is December-April and Wet Period is May-November
- SW1-SW3 is agricultural zone, SW4-SW6 is municipal zone and SW7-SW8 is estuarine zone

3.7 Total coliform bacteria (TCB)

The result of study on the water quality of downstream of Phetchaburi river particularly about total coliform bacteria concentration (TCB) as shown in table 22. An analysis of highlight of total coliform bacteria indicator change in Pechburi river, there were three characteristics such as extreme dry year 2009, heavy rain year 2010, and coldest year 2011. The TCB concentration was low at SW1 and SW2 because it has being agricultural area, and TCB was quite high in SW3 to SW6 due to be municipal areas and SW7 and SW8 be fishery areas. Majority of TCB point sources from Municipal areas and fishery activities. However, average of TCB concentration in Phetchaburi river in during of study and compared with surface water quality standard (20,000 MPN/100ml in class 3) of pollution control department of Thailand, it was considered in class 3 of natural river, which mean that water quality is a medium clean fresh surface water resources, and can use for consumption but it should be passed through an ordinary treatment.

Table 22 TCB (MPN/100ml) highlight of monthly water quality indicators in streamflow of Phetchaburi river as collected during 2006-2013.

Station	Extreme dry year 2009		Heavy rain year 2010		Coldest years 2011	
	Dry period	Wet period	Dry period	Wet period	Dry period	Wet period
SW1	140-3,300	350-7,900	330-5,400	80-5,400	230-16,000	130-5,400
SW2	2,400-16,000	490-16,000	700-9,200	2,400-5,400	3,500-92,000	430-16,000
SW3	2,200-16,000	3,500-92,000	5,400-16,000	1,600-16,000	9,200-35,000	3,500-9,200
SW4	1,700-16,000	490-92,000	1,600-9,200	2,800-24,000	5,400-92,000	5,400-16,000
SW5	940-16,000	790-16,000	1,600-16,000	700-16,000	9,200-92,000	350-160,000
SW6	5,400-92,000	330-54,000	1,400-92,000	5,400-24,000	3,500-54,000	5,400-92,000
SW7	3,500-35,000	3,500-160,000	5,400-22,000	5,400-92,000	3,500-54,000	180-24,000
SW8	3,300-9,2000	330-92,000	5,400-16,000	700-54,000	540-92,000	540-92,000

Note: - Extreme dry Years, Heavy Rainfall Years and Coldest Years were based on statistic of Phetchaburi Meteorological Station between 2005 to 2013

- Dry Period is December-April and Wet Period is May-November
- SW1-SW3 is agricultural zone, SW4-SW6 is municipal zone and SW7-SW8 is estuarine zone.

3.8 Fecal Coliform Bateria (FCB)

In general, fecal coliform bacteria concentrations was low in the first sample station (SW1) in downstream of Phetchaburi diversion dam in each year of highlights of water quality parameters between 2006 to 2103. So that it was identified extreme dry year 2009, heavy rain year 2010, and coldest year 2011 as showed in table 23. The FCB concentration increased as distance and land use areas of Phetchaburi river as well as depend on seasonal condition, FCB was lowest range in SW1 to SW2 due to this areas be agricultural land, for SW3 to SW6 are municipal areas and people have been densely living therefore FCB concentration was higher than SW1 and SW2 before it was slowly decreased when through the fishery areas in SW7 and SW8 before streamflow to Gulf of Thailand. Furthermore, when fecal coliform bacteria are presented in high numbers in a water sample analysis, it means that the water has received fecal matter from one source or another as well as extreme dry, heavy rain and cool water temperature condition have been influenced to Fecal coliform bacteria concentration in Phetchaburi river. Therefore, when comparing FCB concentration of whole in study highlight with surface water quality standard (4,000 MPN/100ml in class 3) of pollution control department of Thailand, it considered in class 3 of natural river, which mean that water quality is a medium clean fresh surface water resources, and can use for consumption but it should be passed through an ordinary treatment.

Table 23 FCB (MPN/100ml) highlight of monthly water quality indicators in streamflow of Phetchaburi river as collected during 2006-2013.

Station	Extreme dry year 2009		Heavy rain year 2010		Coldest years 2011	
	Dry period	Wet period	Dry period	Wet period	Dry period	Wet period
SW1	‹2-110	50-260	80-1,100	‹1.8-2,200	‹1.8-1,400	‹1.8-260
SW2	140-1,400	110-1,800	140-1,400	170-2,200	170-17,000	70-2,200
SW3	260-2,200	330-1,400	1,100-2,200	170-2,200	330-9,400	330-1,700
SW4	140-1,700	70-7,000	170-1,100	170-2,200	330-11,000	260-2,200
SW5	110-5,400	90-2,200	340-2,200	110-2,800	1,700-9,400	170-22,000
SW6	140-2,800	80-11,000	170-28,000	340-2,800	220-17,000	170-3,400
SW7	140-2,200	140-94,000	330-1,100	140-9,400	170-17,000	80-2,700
SW8	260-1,700	‹2-14,000	120-2,200	‹1.8-3,400	33-22,000	270-4,900

Noted: - Extreme dry Years, Heavy Rainfall Years and Coldest Years were base on statistic of Phetchaburi Meteorological Station between 2005 to 2013

- Dry Period is December-April and Wet Period is May-November
- SW1-SW3 is agricultural zone, SW4-SW6 is municipal zone and SW7-SW8 is estuarine zone

3.9 Nitrogen -Nitrate (NO_3-N)

As a result of research on the nitrate concentrations in downstream of Phetchaburi river as illustrated in table 24. In extreme dry year 2009, it was lowest range 0.48-2.10 ml/L and highest range 22.30-62.30 mg/L at SW6 and SW8 respectively in dry period, and it was lowest range 0.46-1.38 mg/L and highest range 0.79-54.95 mg/L at SW5 and SW8 respectively in wet period. In heavy rain year 2010, it was lowest range 0.16-0.99 mg/L and highest range 0.15-72.60 mg/L at SW2 and SW8 respectively in dry period, and it was lowest range 0.43-1.34 mg/L and highest range 0.86-33.80 mg/L at SW3 and SW8 respectively in wet period. In coldest year 2011, NO_3 was low range in municipal area and high concentration in fishery areas like other highlights.

Table 24 NO_3 (mg/L) highlight of monthly water quality indicators in streamflow of Phetchaburi river as collected during 2006-2013.

Station	Extreme dry year 2009		Heavy rain year 2010		Coldest years 2011	
	Dry	Wet	Dry	Wet	Dry	Wet
SW1	0.57-3.35	0.48-2.06	0.20-0.95	0.47-1.59	0.68-0.96	0.58-1.00
SW2	0.57-2.75	0.50-1.68	0.16-0.99	0.43-1.34	0.71-0.88	0.55-0.93
SW3	0.54-2.45	0.46-1.49	0.17-0.95	0.43-1.81	0.75-0.88	0.55-0.93
SW4	0.50-2.36	0.46-1.55	0.20-0.99	0.43-1.88	0.74-0.90	0.52-0.86
SW5	0.50-2.18	0.46-1.38	0.18-1.04	0.43-1.88	0.68-0.90	0.52-0.83
SW6	0.48-2.10	0.50-2.10	0.20-1.04	0.41-1.88	0.65-0.90	0.52-0.79
SW7	9.88-46.5	0.86-17.1	0.21-42.1	0.69-19.6	10.1-22.3	0.70-31
SW8	22.3-62.3	0.79-54.9	0.15-72.6	0.86-33.8	10.6-31.9	0.76-38

Note: - Extreme dry Years, Heavy Rainfall Years and Coldest Years were base on statistic of Phetchaburi Meteorological Station between 2005 to 2013
- Dry Period is December-April and Wet Period is May-November
- SW1-SW3 is agricultural zone, SW4-SW6 is municipal zone and SW7-SW8 is estuarine zone.

However, it was little changed from SW1 to WS6 and it was rapidly changed in SW7 and SW8 before water inflow to the gulf of Thailand. When comparing nitrate concentration values by average with surface water quality standard (5.0 mg/L in class 3) of pollution control department of Thailand, it considered in class 3 of natural streamflow, which mean that water quality is a medium clean fresh surface water resources, and can use for consumption but it should be passed through an ordinary treatment

3.10 Nitrogen -Ammonia (NH_3-N)

The concentration of nitrate-ammonia (NH3-N) that was studied and analyzed in duration of study 2006 to 2013 in the downstream of Phetchaburi river but it has taken some year that was highlight of water quality as seasonal change and land use areas including extreme dry year 2009, heavy rain year 2010, and coldest year 2011 as showed in table 25. In extreme dry year 2009, NH_3 was lowest range 0.00-0.67 mg/L and highest 0.2.16 mg/L at SW1 and SW8 respectively in dry period, and other highlight years of water quality indicator in similar change and the major was low concentration of NH3 in SW1 and to be high in SW8 so that land use has influenced to water quality indicators of Phetchaburi river. However it was still under criteria of the surface water quality standard (0.5 mg/L) of pollution control department of Thailand. In general, it was considered in type 3 of natural rivers.

Table 25 HN_3 (mg/L) highlight of monthly water quality indicators in streamflow of Phetchaburi river as collected during 2006-2013.

Station	Extreme dry year 2009		Heavy rain year 2010		Coldest years 2011	
	Dry	Wet	Dry	Wet	Dry	Wet
SW1	0.00-0.67	0.11-1.72	0.03-0.26	0.03-0.19	0.01-0.25	0.03-0.13
SW2	0.03-0.78	0.20-0.98	0.02-0.41	0.05-0.17	0.01-0.24	0.03-0.14
SW3	0.07-0.50	0.13-0.83	0.01-0.04	0.04-0.23	0.02-0.23	0.04-0.16
SW4	0.03-0.48	0.02-0.83	0.02-0.31	0.03-0.27	0.02-0.17	0.04-0.19
SW5	0.04-0.56	0.17-0.87	0.00-0.31	0.03-0.32	0.03-0.25	0.11-0.21
SW6	0.08-0.58	0.04-1.06	0.01-0.33	0.03-0.23	0.05-0.25	0.12-0.24
SW7	0.17-1.67	0.14-0.97	0.03-3.90	0.04-0.22	0.06-0.45	0.05-0.23
SW8	0.00-2.16	0.15-1.67	0.16-4.80	0.12-0.34	0.10-0.64	0.13-0.58

Note: - Extreme dry Years, Heavy Rainfall Years and Coldest Years were base on statistic of Phetchaburi Meteorological Station between 2005 to 2013
- Dry Period is December-April and Wet Period is May-November
- SW1-SW3 is agricultural zone, SW4-SW6 is municipal zone and SW7-SW8 is estuarine zone

On the other hand, there was report on the surface water quality of environmental agency region 8, Ministry of Natural Resources and Environment (2012) stated that the result of surface water quality monitoring in Petchaburi Basin from 10 water quality monitoring stations, there are 3 stations on the upper river and 7 stations on the lower river. In general, as the result of that monitoring revealed that all of water quality from all stations were lower than the surface water quality standard 100% and 4 stations in lower river there were water quality indicator values were lower than the standard 57.14 % by average, the water quality from 7 stations is lower than standard 70 % including dissolved oxygen (DO), Biochemical Oxygen Demand (BOD), Total Coliform Bacteria (TCB) and Fecal Coliform Bacteria (FCB) are the water quality index of major problems.

4. Dilution Process and Water Management

4.1 Accident rainstorm and flash flood

Experiences from field inventory found that the flow rate plays vital role in handling water from Phetchaburi diversion dam which is normally controlled under needs of water consumers. Based on flood problems along riverbanks and cities as well as municipals, flow rate can be classified as the averaging value of 15 m^3/s (ranging 5-50 m^3/s) for normal flow, 75 m^3/s (ranging 50-150 m^3/s) for warning flow, 200 m^3/s (ranging 150-250 m^3/s) for risky flow, and more 250 m^3/s for critical flow (Chunkao 2010, Linsley *et al.*, 1988, Loomis *et al.*, 2000, Mangimbulude *et al.*, 2012, Mathews and Richter 2007, Postel and Richter 2003, Tanji *et al.*, 2006 and Vagnetti *et al.*, 2003, Wahla and Kirkham 2008, Wang *et al.*, 1978 and Wang *et al.*, 2010). In other words, the normal flow which was drained from Phetchaburi Diversion dam could be neglected in flood along the stream banks, spot-area flood occurring under warning flow, small-low-flat land flooding from risky flow, and riverbank-settlement areas inducing flood from critical flow. This is why flash floods were accidentally occurred on 7-9 November 2013 because of heavy rainstorms striking all over the provinces of Phetchaburi, Prachuab Kirikhan, Ratchburi, and Smut Songkram that the Kaeng Krachan reservoir and Phetchaburi diversion dam had to release the excess rainwater with high flow rate up to 377 m^3/s. It would be emphasized that the heavy rainstorm provided plenty of clean water which is the best diluting water for reducing stream pollution likewise Phetchaburi river, especially in summer time and some water shortage period in wet season as well as the time for irrigating period on second crop growing.

4.2 Water temperature

As result of study was showed in figure 22, in general, the water temperature change slowly increased 29.6 to 30.2°C from SW1 to SW8 respectively, when there was normally water flow (22.4 m^3/s) in normal of wet season. Water temperature fluctuated and highest 28.8 °C at SW7 and lowest 27.5 °C at SW2 when water flow quantity (100 m^3/s) in medium of wet period; and there was water flow (377 m^3/s) in highest of wet season, it was lowest 25.0 °C at SW4 and highest 27.7°C at SW1. So that the water temperature change was not much different in during study, however, the water temperature change has influence to some water quality indicators such as DO, EC and etc. In addition to, the changing water temperature was influenced from weather condition and sunlight in during of water sample collection in the real field area condition in Phetchaburi river, and also water temperature exerts a major influence on biological activity and growth. Temperature governs the kinds of organisms that can live in rivers and lakes. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have a preferred temperature range. Factors that affect water temperature included air temperature, amount of shade, soil erosion increasing turbidity, thermal pollution from human activities, and confluence of streams.

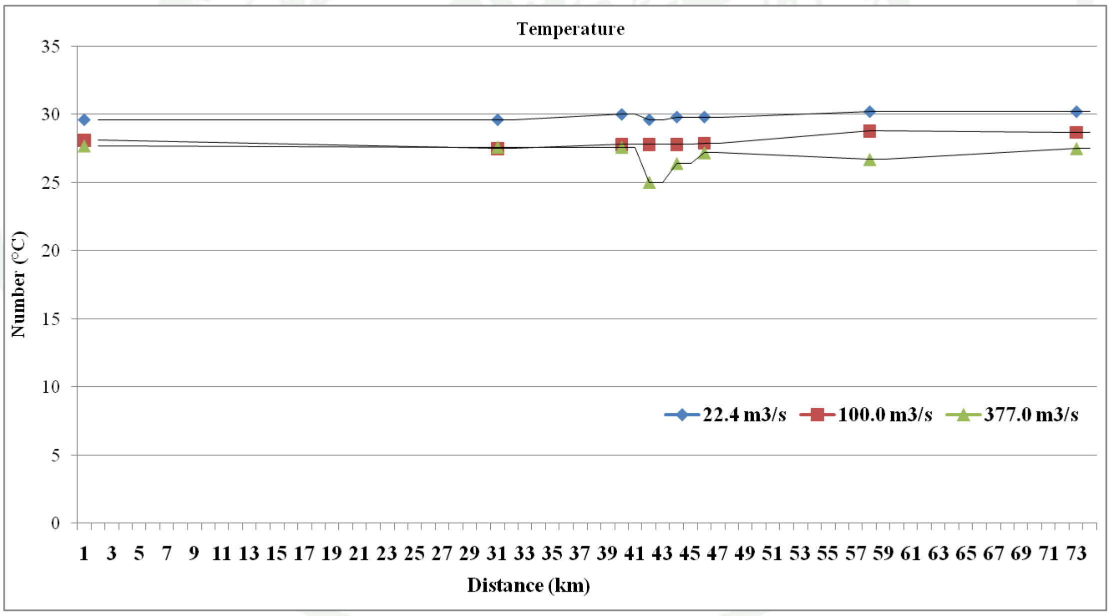


Figure 22 Relationship between streamflow velocity and the values of water temperature along the sampling points as localized on various distance from Phetchaburi diversion dam throughout to outlet.

4.3 pH

The pH value concentration in different water flow in normal, medium and high levels (flash flood condition) of wet seasons such as (22.4 m^3/s, 100 m^3/s and 377 m^3/s) respectively, the pH values was slowly decreased 7.6 to7.4 when water flow (22.4 m^3/s) through SW1 to SW3 respectively which it was in agricultural areas, and it was slightly increased 7.4 to 7.7 from SW4 to SW7 respectively and it was 7.3 at SW7 and SW8. Water flow (100 m^3/s) pH value ranged from 7.3-8.0 at SW1 to SW8 that reached agricultural land , municipal areas and fishery areas, and pH value changed fluctuation when water flow (377 m^3/s) and ranged 7.6 - 7.9. However, all of pH concentration values were under criteria of surface water quality standard (pH = 5 - 9) of pollution control department of Thailand in during of study, which it showed in figure 23. In fact, the pH is significant that determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc). Addition to, water temperature has been influenced to an increase and decrease of pH in water, when pH of water decrease with water temperature increase, if clear water pH is 7, and pH is less than 7 is acid and more than 7 is base, so that pH found from this study more than 7, all of water flow 22.4, 100 and 377 m^3/s of Phetchaburi river.

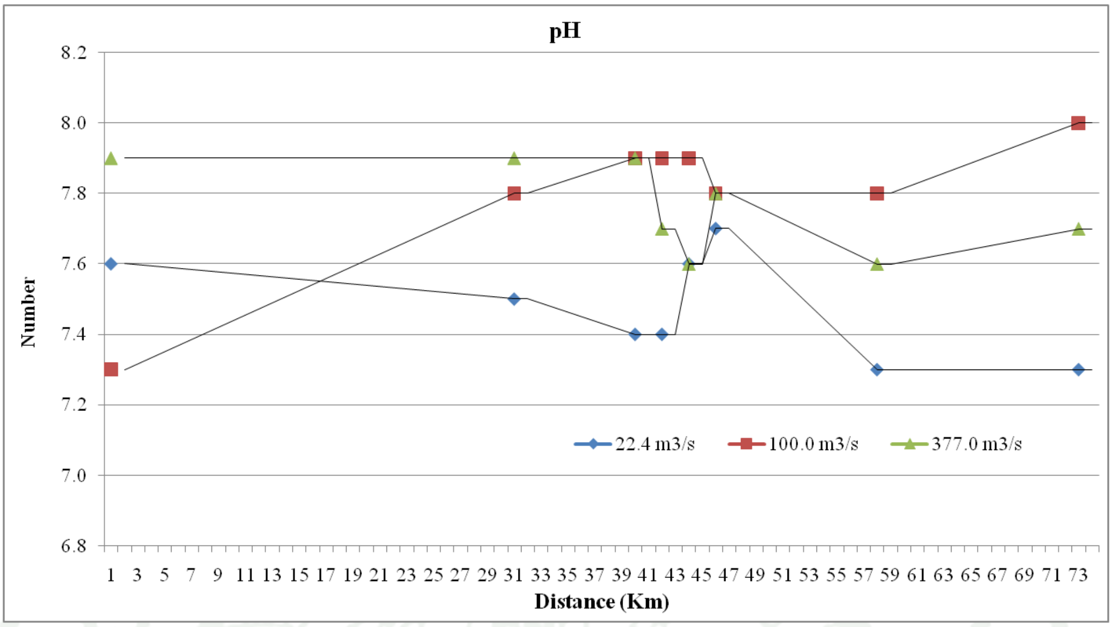


Figure 23 Relationship between streamflow velocity and the values of pH along the sampling points as localized on various distance from Phetchaburi diversion dam throughout to outlet.

4.4 Dissolved oxygen and biochemical oxygen demand

It is observed that all indicators for indicating the existing water quality in streamflow of Phetchaburi river did not look like polluted water even if the existence of some physical, chemical, and biological contaminants but their differences have been evident under the conditions of flow velocity as sampled at 22.4, 100, and 377 m^3/s. As stated before, BOD and DO were taken in representing water quality rather than the other indicators. For normal flow (22.4 m^3/s), the values of BOD in drained water from Phetchaburi diversion dam were gradually increased and opposite to DO because they were getting close to the denser population areas which polluted organic wastes and other contaminants becoming more and more, while DO was used for bacterial organic digestion processes (Cazelles *et al.*, 1991, Chen *et al.*, 2008, Chunkao *et al.*, 2012, Penha-Lopes *et al.*, 2011). The situation became worse when the said mass flow got close to the city zone (municipal zones) at the distance range between km 39th to km 45th by increasing BOD and decreasing

DO. Then after, BOD was rapidly increased while DO drastically decreased in estuarine zone at km 72^{nd} according to two causes: firstly, this river reach is not only obtained organic and inorganic contaminants from upstream municipals but also still high dense population to pollute the stream water; and the second, the estuarine zone is consisted of saline water which plays significant role in inhibiting bacterial organic digestion process but more DO are utilized as energy for the said process (Wang *et al.,* 1978, Wahla and Kirkham 2008, Vagnetti *et al.*, 2003, Tanji *et al.,* 2006).

When flow velocity increases up to 100 m^3/s, some part of riverbank areas were submerged with excess water from the river in which the stream water pollutants had to accepted the debris, eroded soils, organic wastes, toxic and non-toxic chemicals, microorganisms, and nematodes without any doubts. That is the reason why BOD was low at the time of draining, then it has been gradually increased until it reached at about 10 km before entering to urban areas, that is, BOD 2.9 mg/L Phetchaburi dam (SW1) to increase up to BOD 4.9 mg/L at (SW2), and going down to SW3. The BOD values at SW3 point were still decreased about 2.5 mg/L, 2.2 mg/L at SW4, 2.4 mg/L at SW5, and 2.9 mg/L at SW6 but it became 1.6 mg/L at SW7 and going up to 4.4 mg/L at SW8 as the maximum value because of estuarine effluences (Tanji *et al.*, 2006, Srigate, 2009, Robinson and Maris, 1985, and Postel and Richter, 2003). However, DO was gradually decreased from Phetchaburi diversion dam to the outlet, only city zone found an increase while BOD decreased since the measuring point SW3 is located at the bridge nearby Big-C Super Market that expected to pollute much more organic waste in streamflow (Penha-Lopes *et al.*, 2011, Mangimbulude *et al.,* 2012). The said condition can encourage some amount of DO for serving the bacterial organic digestion processes that the reason why DO decrease throughout the river of Phetchaburi. It is remarkable for careful observation when flow velocity increased up to 377 m^3/s that trends of BOD and DO looked the same down slope due to much more rainwater of heavy rainstorm is usually plenty of DO and also increasing BOD in stream water. For this reason, the decrease of DO because it was used for bacterial organic digestion process that made BOD lowering as well but interesting point was on the city zone in terms of urban rainwater in city zone being composed of DO while drastic increases of BOD was occurred by erosion process due to much more excessive rainwater on the ground surface with very less infiltration rate (Loomis *et al.*, 2000, Liu *et al.*, 2009, Burnett *et al.*, 2007, Cazelles *et al.*, 1991, Chen *et al.*, 2008, Chu *et al.*, 2010, LERD 2012, Mangimbulude *et al.*, 2012, Rakthai 2012, and Kraus *et al.*, 2014). Details of DO and BOD change as showed in figure 25.

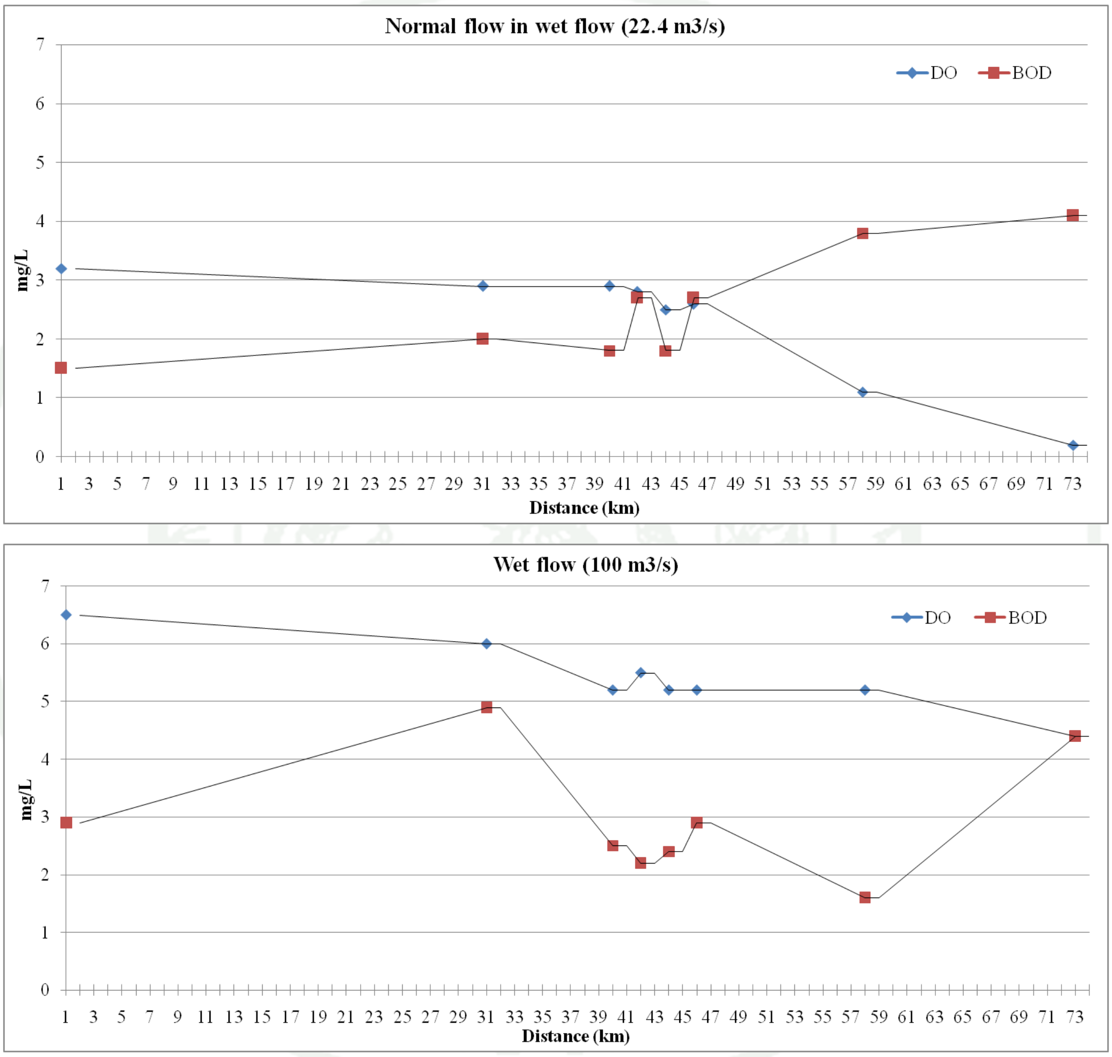


Figure 24 Relationship between streamflow velocity and the values of BOD and DO along the sampling points as localized on various distance from Phetchaburi diversion dam throughout to outlet.

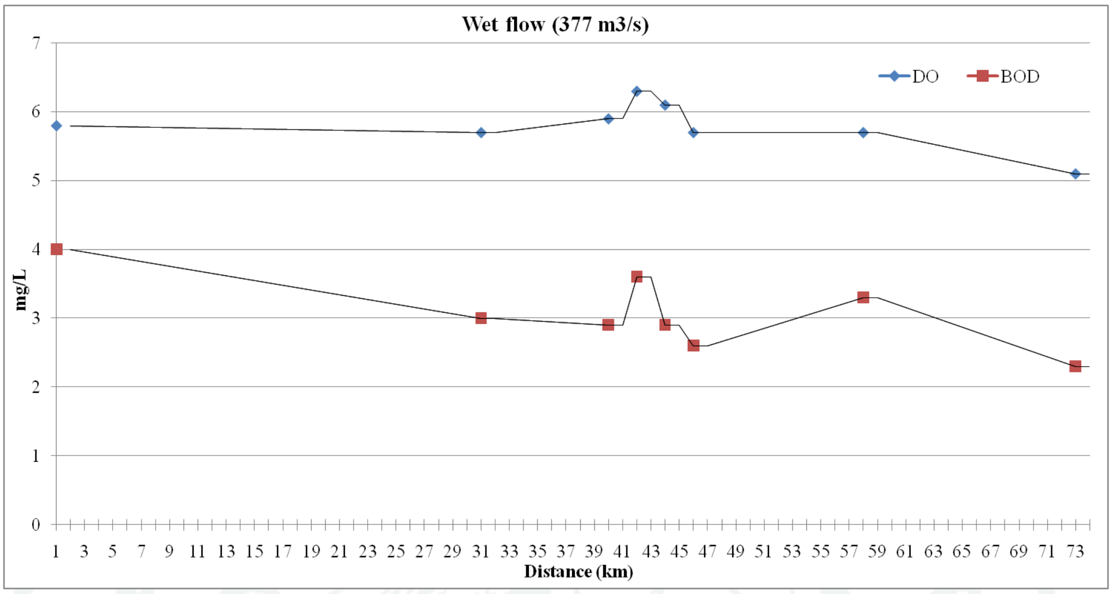


Figure 24 (Continued)

4.5 Total dissolved solid

For the result of study on the total dissolved solid (TDS) as showed in figure 25, when water flow in normal (22.4 m^3/s), TDS value fluctuated 121 mg/l at SW1 and decreased 120 mg/l at SW4 then increased 2,544 mg/l at SW8 before water flow to gulf of Thailand. At the same way, increasing water flow (100 m^3/s) TDS was slowly increased 160 mg/l to 215 mg/l from SW1 to SW8 respectively, and water flow (377 m^3/s) TDS value was not different from normal water flow through SW1 to SW6 but it was very different from SW7 and SW8. So that there was much water flow had influenced to TDS values as well as water quality along Phetchaburi river particularly in downstream of Phetchaburi river before water flow reached to Gulf of Thailand. The TDS concentration values had inhibition from salinity that coming from Gulf of Thailand around the Ban lam district at SW8. However, when much water flow particularly during flood (377 m^3/s) leached sources of total solids include industrial discharges, sewage, fertilizers, road runoff, and soil erosion and higher concentrations of suspended solids can serve as carriers of toxics, which readily cling to suspended particles, particularly a concern where pesticides are being used on irrigated crops and where solids are high, pesticide concentrations may increase well beyond those of the original application as the irrigation water travels down irrigation.

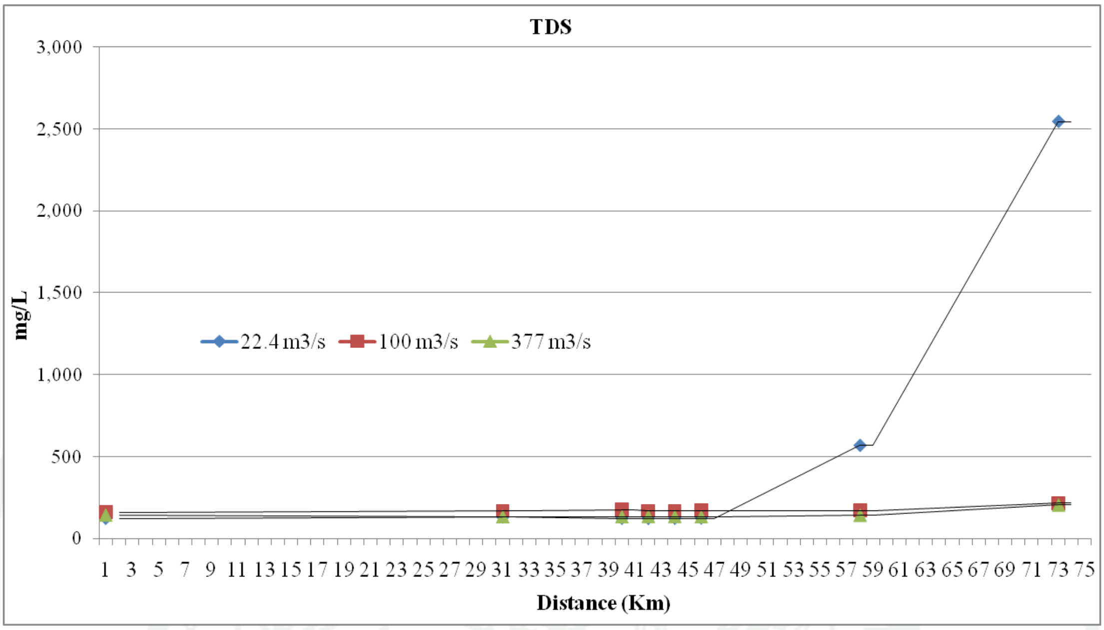


Figure 25 Relationship between streamflow velocity and the values of TDS along the sampling points as localized on various distance from Phetchaburi diversion dam throughout to outlet.

4.6 Electrical conductivity

As a result of study illustrated that in general, the electrical conductivity (EC) values were not very different in each station during study from SW1 to SW6 including 3 times of water flow (22.4 m^3/s, 100 m^3/s and 377 m^3/s), but they were very different in SW7 and SW8 between normal and medium and high level of water flow, which it was highest 3,420 µS/cm at SW8 of water flow (22.4 m^3/s) and it was only 320 µS/cm and 306 µS/cm of water flow (100 m^3/s and 377 m^3/s) respectively as showed in figure 26. However, EC was not identified in surface water quality standard of Pollution Control Department of Thailand. But EC was very important and to be affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminium captions. Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature such as warmer the water, the higher the conductivity. Electrical conductivity in streams and rivers also was affected primarily by the geology of the area through which the water flows. On the other hand, streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water.

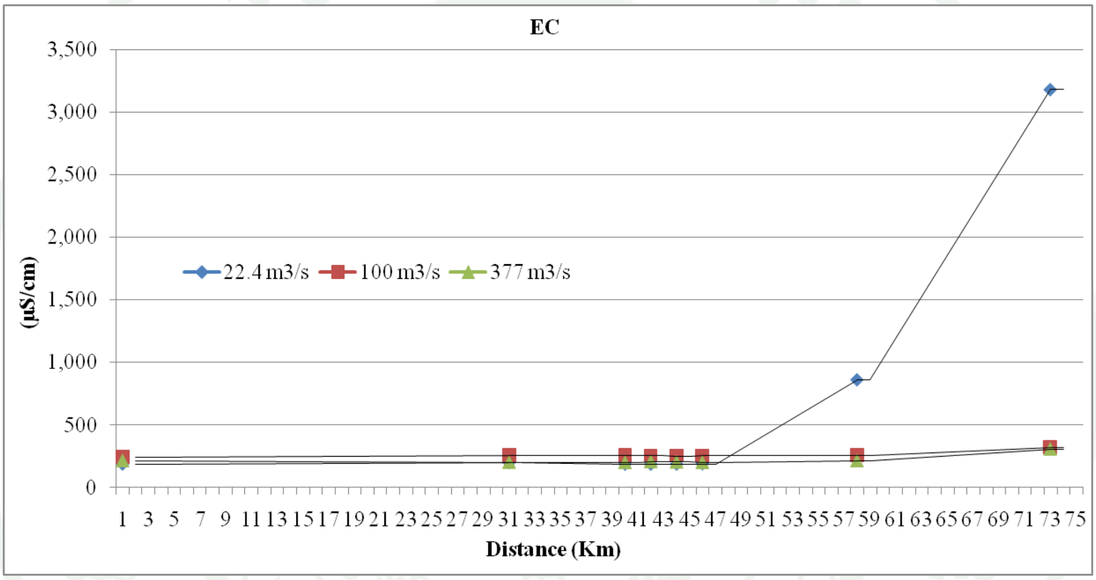


Figure 26 Relationship between streamflow velocity and the values of EC along the sampling points as localized on various distance from Phetchaburi diversion dam throughout to outlet.

4.7 Nitrate-nitrogen

The nitrate-nitrogen value concentration was slightly increased 0.62 mg/l - 5.30 mg/l from SW1 to SW8 respectively as distance of Phetchaburi river when water flow (22.4 m^3/s), the water flow (100 m^3/s) NO_3-N values was slowly increased 1.20 mg/l to 1.40 mg/l from SW1 to SW8 respectively, and water flow (377 m^3/s) it was fluctuated and lowest 0.67 mg/l at SW1 and highest 0.82 mg/l at SW6 respectively. So that the much water flow (water rain) had influenced to water quality especially nitrate-nitrogen values in downstream of Phetchaburi river. It showed in figure 27 on the change of nitrate-nitrogen concentration in different water flow quantity.

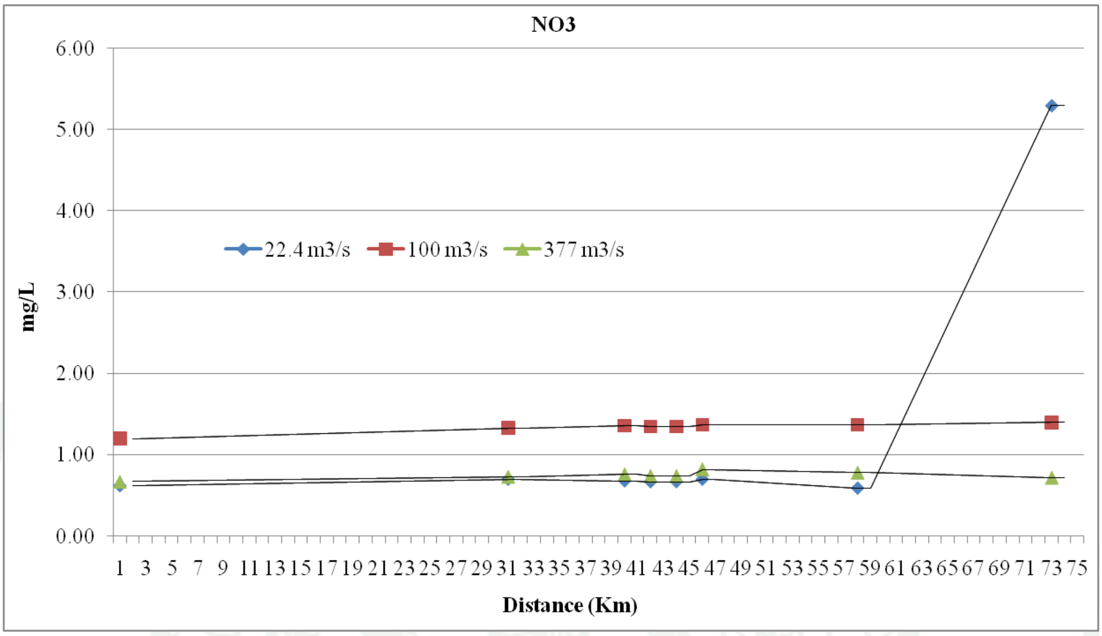


Figure 27 Relationship between streamflow velocity and the values of NO_3 along the sampling points as localized on various distance from Phetchaburi diversion dam throughout to outlet.

However, it was under criteria of surface water quality standard of Pollution Control Department of Thailand (5.0 mg/L in type 3 of surface water quality). On the other hand, NO_3-N is found in several different forms in terrestrial and aquatic ecosystems. These forms of nitrogen include ammonia (NH3), nitrates (NO3), and nitrites (NO2). Nitrates are essential plant nutrients, but in excess amounts they can cause significant water quality problems. Together with phosphorus, nitrates in excess amounts can accelerate eutrophication, causing dramatic increases in aquatic plant growth and changes in the types of plants and animals that live in the stream and rivers. This, in turn, affects dissolved oxygen, temperature, and other indicators. Excess nitrates can cause hypoxia (low levels of dissolved oxygen) and can become toxic to warm-blooded animals at higher concentrations. The majority of sources of nitrates include wastewater treatment plants, runoff from fertilized lawns and cropland, failing on-site septic systems, runoff from animal manure storage areas, and industrial discharges that contain corrosion inhibitors.

4.8 Nitrogen-ammonia

For Ammonia-nitrogen concentration was slightly increased from 0.04-0.22 mg/l at SW1 to SW8 respectively in normal of wet season (22.4 m^3/s), and it was clearly changed when increase water flow (100 m^3/s and 377 m^3/s), NH_3-N was not detected in wet season (flash flood), and it was clearly diluted when the water flow increasing from normal to higher levels. However, in particularly, the NH3-N concentration was under the criteria of surface water quality standard of pollution control department of Thailand (NH_3 = 0.5 mg/L for type 3 of surface water quality) as showed in figure 28. An ammonia-nitrogen is an inorganic, dissolved form of nitrogen that can be found in water and is the preferred form for algae and plant growth, and it is the most reduced form of nitrogen and is found in water where dissolved oxygen is lacking. When dissolved oxygen is readily available, bacteria quickly oxidize ammonia to nitrate through a process known as nitrification. Other types of bacteria produce ammonia as they decompose dead plant and animal matter. Addition to, NH_3 has been depending on temperature and pH, high levels of ammonia can be toxic to aquatic life. High pH and warmer temperatures increase the toxicity of a given ammonia concentration. High ammonia concentrations can stimulate excessive aquatic production and indicate pollution. Important sources of ammonia to lakes and streams can include: fertilizers, human and animal wastes, and by products from industrial manufacturing processes. Techniques to prevent high ammonia concentrations involve filtration of runoff water especially from farms and other areas where animals may be kept in larger numbers, proper septic system maintenance, and not over-fertilizing yards or fields.

Q (m3/s)	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
22.4	0.04	0.05	0.06	0.08	0.12	0.13	0.13	0.22
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
377	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 28 Relationship between streamflow velocity and the values of NH_3 along the sampling points as localized on various distance from Phetchaburi diversion dam throughout to outlet.

4.9 Total coliform bacteria

The result of study on the TCB concentration values, when water flow from Phetchaburi diversion dam (22.4 m^3/s), in general, TCB concentration fluctuated in along the Phetchaburi river, which was lowest 5,400 MPN/100ml at SW2 and SW8, and it was highest 16,000 MPN/100ml at SW3 and SW5. When increasing drainage (100 m^3/s), TCB concentration from 5,400 MPN/100ml at SW1 and slightly increased 9,200 to 16,000 MPN/100ml at SW2 and SW3 respectively before it was decreased 3,500 and 2,800 MPN/100ml at SW4 and SW5 respectively and increased 9,200 MPN/100ml at SW7 while TCB concentration was highest 92,000 MPN/100ml at SW1 upon water flow increase (377 m^3/s), was 54,000 MPN/100ml at SW3 and slowly decreased to 3,500 MPN/100ml at SW8 as showed in figure 29. However, all of TCB values were different when there were different water inflows from Phetchaburi diversion dam. Although they are generally not harmful themselves, they indicate the possible presence of pathogenic (disease-causing) bacteria, viruses, and protozoans that also live in human and animal digestive systems. Therefore, their presence in streams suggests that pathogenic microorganisms might also be present. Since it is difficult, time-consuming, and expensive to test directly for the presence of a large variety of pathogens, water is usually tested for coliforms and fecal streptococci instead. In addition to the possible health risk associated with the presence of elevated levels of fecal bacteria, they can also cause cloudy water, unpleasant odors, and an increased oxygen demand. Sources of fecal contamination to surface waters include wastewater treatment plants, on-site septic systems, domestic and wild animal manure, and storm runoff.

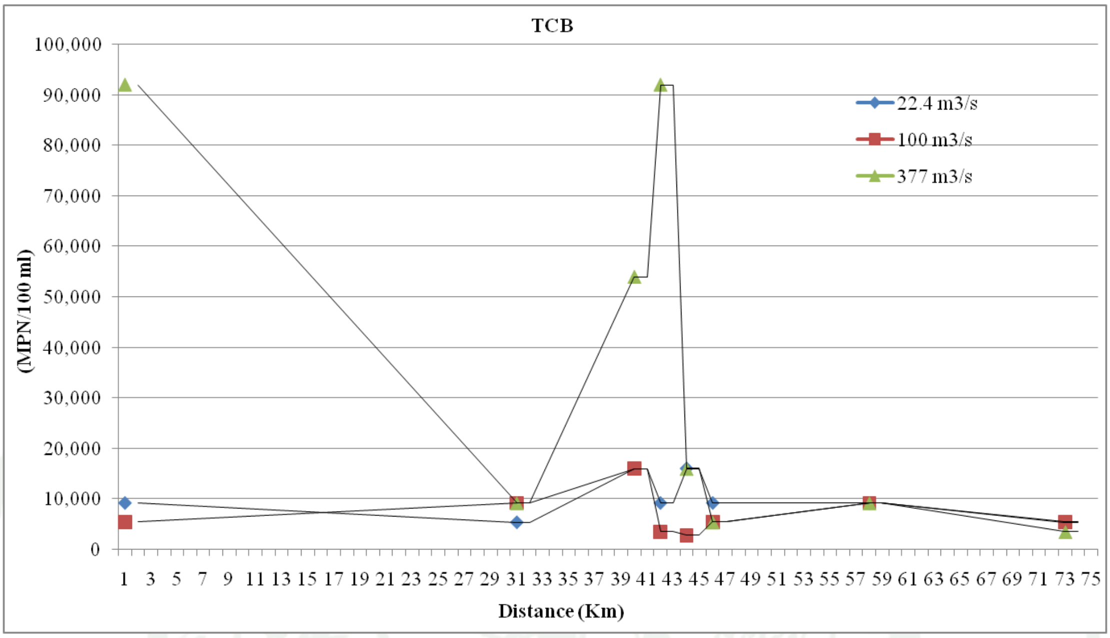


Figure 29 Relationship between streamflow velocity and the values of TCB along the sampling points as localized on various distance from Phetchaburi diversion dam throughout to outlet.

4.10 Fecal coliform bacteria

The fecal coliform bacteria concentration values in case study on the different stream flow such as in normal, medium and high stream flow of wet season, FCB value ranged 230 - 2,800 MPN/100ml when water flow quantity (22.4 m^3/s) and it was lowest 230 MPN/100ml at SW4 and highest 2,800 MPN/100ml at SW3. When increasing water flow (100 m^3/s), FCB concentration level ranged 170-1,800 MPN/100ml, it was lowest 170 MPN/100ml at SW5 and highest 1,800 MPN/100ml at SW3. While accident flash flood and there was drainage from Phetchaburi diversion dam (377 m^3/s), and it ranged 490-17,000 MPN/100ml and it was lowest 490 MPN/100ml at SW8 and highest 17,000 MPN/100ml at SW1 and SW3. Which it observed that water flow increasing has been influenced to FCB as along the

Phetchaburi river. However, the FCB concentration values along river there were some areas over the standard of surface water quality and some areas were under criteria of standard as showed in figure 30. The presence of fecal coliform bacteria in aquatic environments indicates that the water has been contaminated with the fecal material of human or other animals. At the time this occurred, the source water may have been contaminated by pathogens or disease producing bacteria or viruses which can also exist in fecal material. Some waterborne pathogenic diseases include typhoid fever, viral and bacterial gastroenteritis and hepatitis. The presence of fecal contamination is an indicator that a potential health risk exists for individuals exposed to this water and occur in ambient water as a result of the overflow of domestic sewage or nonpoint sources of human and animal waste.

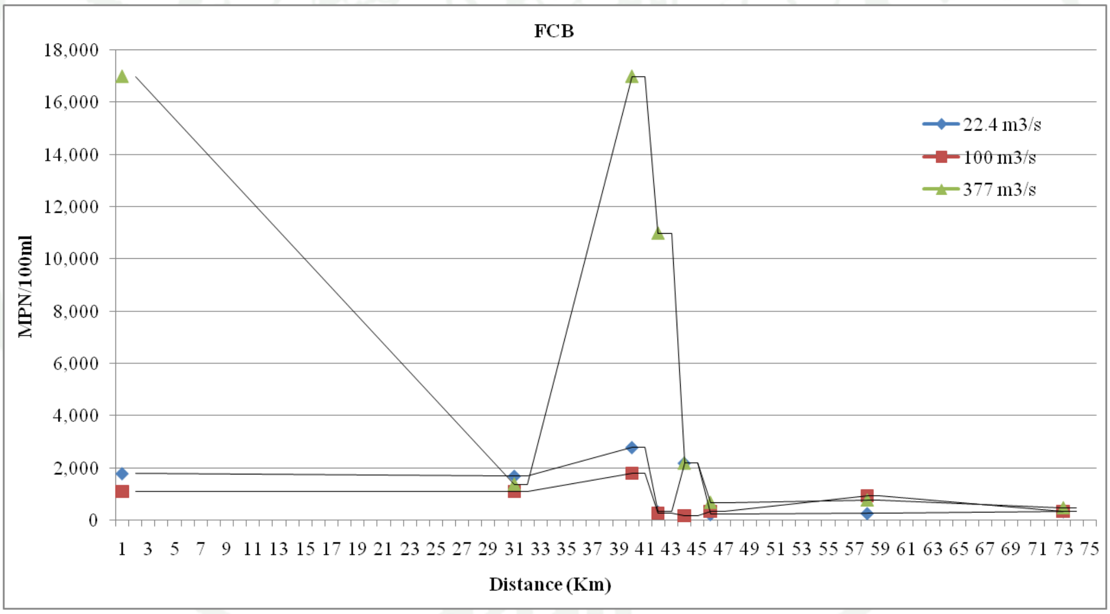


Figure 30 Relationship between streamflow velocity and the values of FCB along the sampling points as localized on various distance from Phetchaburi diversion dam throughout to outlet.

Discussion

Closely study on previous water quality analysis in relation to flow measurement and stream pollution in Phetchaburi river from beginning up to the present time, it should be emphasized due to obtain the key productive results as indicated by sensitive indicators of water temperature, pH, TDS, BOD, DO, EC, NO_3, NH_3, TCB and FCB concentration that Phetchaburi diversion dam manager has provided nourishment of Phetchaburi river with running all year round, except for a short time in running dry stream. Pulling apart of streamflow as drained from Phetchaburi diversion dam to the double-crop farmlands has to be carefully considered to have water enough for feeding Phetchaburi river in maintaining the riverine ecosystems all the way to the river mount. Following Chunkao (2008) and Chunkao et al (1981), watershed as a unit area for water management in terms of water quantity, desirable water quality, and water flow regime in which the irrigation watershed management can be applicable in managing quantity water flow in Phetchaburi river together with governing flow regime. Thus, well-planned management of irrigation watershed could be affected on water yields (water quantity, quality and flow regime) to take in irrigated areas without water shortage even in climatic condition of drought.

Luckily, headwater of Phetchaburi irrigation watershed has been covered with tropical rainforest which is characterized as moist, 12-month rain falling, high amount of rainfall, high rainfall intensity going hand-in-hand with long duration, and less evapotranspiration, and narrow different maximum and minimum temperature. It is astonished in Kaeng Krachan rainforest trees to condition in soils to be friable, more soil porosity, high organic matter content, and deep profile on which they are satisfied for high water holding capacity, that is, absorbing much more rainwater before releasing to stream (Chunkao 2008, Chunkao et al 1981, Baver 1968, Baver et al 1972, Linsley et al 1988, Loomis et al 2000, Mathews and Richter 2007, and Postel and Richter 2003). Consequently, the water as kept in soils (three forms: chemical combined water, soil pores, and coating on surface of soil particles) is normally supplied to Kaeng Krachan reservoir without shortage even in very dry period of summer time (Baver 1968, Baver et al 1972, Chunkao 2008, and Linsley et al 1988). The aforesaid statements are brought to emphasize that the failure of dilution process for eliminating stream pollution of Phetchaburi river is depended on managing water of Phetchaburi diversion dam rather than water shortage in Kaeng Krachan reservoir as supply sources. Eventually, keeping Kaeng Krachan National Park green (more 50 % cover) is beyond the handling water at Phetchaburi diversion dam according to support the rainforest soils for increasingly absorbing rainwater before releasing to store in Kaeng Krachan reservoir and following to transfer to Kaeng Krachan diversion dam before providing nourishment of Phetchaburi river with continuous flow (more or less 30 m^3/s) throughout the estuarine at river mouth.

On the other hand, the water quality management by water flow quantity can dilute and control it as Elisabeta *et al.*, (2011) indicated that dilution and neutralization are successful in reducing concentration, with difference of timing, affected river length and additional discharge. Adding clean water to the river causes water flow increase, which results on one side on pollutant dilution and on the other side on velocity and dispersion coefficient increase. Water flow from dams and other river structures change the downstream flow patterns and consequently affect water quality, temperature, sediment movement and deposition, fish and wildlife, and the livelihoods of people who depend on healthy river ecosystems and water flows seek to maintain these river functions (Mathews and Richter, 2007). In the effort to manage water to meet human needs, the needs of freshwater species and ecosystems have largely been neglected, the water management is a method including the controlling water flow, natural water treatment and soil erosion (Loomis et al., 2000) in fact ecological values are very important for aquatic habitat and organisms when there were water resources utilization over the carrying capacity of recovery as natural condition (Chunkao, 2001). Water resources deterioration, it was affected to the aquatic ecology such as Phetchaburi river, it had biochemical oxygen demand (BOD) concentration 7.36 mg/l by average along the river (LERD, 2010).

CONCLUSION AND RECOMMENDATION

Conclusion

As the result of the investigation on the watershed management for controlling water quality in the downstream of the Phetchaburi river in Phetchaburi province, Thailand. This study focused on three main purposes included water management in upstream of Phetchaburi diversion dam, studied and analyzed on the water quality in downstream of Phetchaburi river, and studied on the controlling water quality by water management in upstream particularly water flow from Phetchaburi diversion dam. Which an investigation on managing water flow from Phetchaburi diversion dam was concentrated in the relationship between flow velocity control and dilution capacity of stream pollution, especially in the period of water shortage from irrigating much more water to double-crop rice fields and also running dry of stream in summer time. To achieve the target, the stream water quality and streamflow measurement as recorded in previous analysis was taken in in-depth understanding together with updated researches and also study on accidental heavy rainstorm to be included the resulting flash flood in agricultural, city, and estuarine zones. Due to the water quality indicators (BOD, DO, TDS, total dissolved solid, pH, temperature, total coliform bacteria, fecal bacteria) which they showed any differences in decrease and increase tendency, therefore, all of water quality indicators were selected as the representatives for determining flow and dilution capacity while the water flows all the way from Phetchaburi diversion dam throughout agricultural, city, and estuarine zones. The research results was concluded as follows:

1. Most of water quality indicators in Phetchaburi river from Phetchaburi diversion dam all the way to all-year-cropping agricultural, dense-populated city/municipals, and estuarine zones were useable for any consumption, except in dry period and the period of taking apart much more water to double-crop fields for growing rice and some other cash crops.

2. An increasing flow velocity from 22.4 m^3/s to 100 m^3/s and jumping up to 377 m^3/s were evidently resulted in high capacity of stream pollution by dilution process but flash floods occurring on riverbanks and the dense-populated communities in downstream areas, particularly municipality of Thayang, Ampoe Muang Phetchaburi, and Ban Laem districts.

3. Although the higher flow velocity, 100 and 377 m^3/s, was shown the better results in dilution processes than less speed, the flash floods impacted on tangible and intangible losses. Therefore, the better capacity of dilution process is recommended to keep flow rate less than 30 m^3/s in dry period and less than 10 m^3/s in wet period.

4. Well-planned management of forest cover more or less 50 % of irrigation watershed area should be the most probable areal size keep water in soils in order to serve the necessity of water consumption without anytime of shortage.

Recommendation

According to field study, the Phetchaburi irrigation project is a main organization for water management in upstream of Phetchaburi river for water distribution for all of water use sectors such as agricultural production, people's water consumption in Hua Hin district, and maintaining ecosystem. As the result of investigation found that the water quality was quite degraded in dry season and water flow from Phetchaburi diversion dam was quite limited for maintaining ecological conservation. So that it is possible, we should control water quality by more than normal drainage to downstream for dilution of some water quality indicators especially in dry period. However, it depends on the decision of authorities of Irrigation project and stakeholder organizations should set up the plan together about water management.

In addition to, we should control point sources of wastewater that has been discharged to the Phetchaburi river such as control point sources from community zones, mitigating point sources from agricultural production factors and natural sources. For wastewater from municipals we should have municipal wastewater treatment in villages or communities, pond treatment system in households, may be should have two kinds of wastewater treatment system by nature and man-made including drainage canal construction of communities and link with each household, markets, and other places after that link to wetlands, ponds treatment systems before wastewater is discharged to natural rivers. For point sources from agricultural production factors, we should have measures to mitigating point sources from chemical application such as chemical fertilizers, pesticides and insecticides by utilize organic fertilizers and organic pesticides instead.

Moreover, there are many programs and projects that development on the water resources in the Phetchaburi watershed area including operation and maintenance of water resources, water drainage and distribution system , water resources reservation system and other projects and total 55 projects under responsibility of Department of Irrigation; rehabilitation of natural water resources and other projects total 26 projects under responsibility of Department of water resources and also 3 projects or programs under responsibility of Department of wildlife and plant park, which all projects should have cooperation with each other including establishing integrated management plan, share activities for implementation about water resources management as well as controlling and mitigating impacts to water quality in downstream of Phetchaburi river.

LITERATURE CITED

Anderson, S.D. 1999. **Watershed Management and Nonpoint Source Pollution**: The Massachusetts Approach. Originally published in the Boston College Environmental Affairs Law Review, United States

American Public Health Association, American Water Works Association and Water Pollution Control Federation. 1998. **Standard Methods for the Examination of Water and Wastewater**. American Public Health Association. Washington, D.C.

APHA. 1992. **Standard methods for the examination of water and wastewater**. American Public Health Association, 18th ed. Washington, DC.

APHA.AWWA.WEF. 2005. **Standard Method for the Examination of Water and Wastewater**. America Public Health Association, American Water Works Association and Water Environment Federation, 21th ed, Washington, DC,

APHA. 1995. **Standard methods for the examination of water and wastewater**, 19th Edition. American Public Health Association, Bauer, S. B., and T.A. Burton. Washington, DC.

American Water Works Association. 1999. Water Quality & Treatment: **A Handbook of Community Water Supplies.** New York, NY: McGraw-Hill Handbooks.

Ani, E. C., V. M. Cristea, P. S. Agachi. 2011. **Process Engineering tools to reduce river in-stream pollution.** Babe Bolyai University Cluj Napoca, Faculty of Chemistry and Chemical Engineering 11, Arany Janos, 400028, Cluj Napoca, Cluj, Romania.

Azene, B and K. Gathriu. 2006. **Participatory watershed management**: Lessons from RELMA's work with farmers in eastern Africa, ICRAF working paper no.22, world agro forestry center, Nairobi

Asriningtyas, V., C. Meesukko, N. Gajaseni, and A. Voinov. 2006. **Seasonal Water Flow Trends in Conjunction with Phytoplankton Biovolume** in Phetchaburi River, Thailand.

Borbor-Cordova, M. J., E. W. Boyer, W. H, McDowell and C. A. Hall. 2006. **Nitrogen and phosphorus budgets for a tropical watershed impacted by agricultural land use**: Guayas, Ecuador. Biogeochemistry. 79:135–161.

Bartram and Balance. 1996. **Water Quality Monitoring-** A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes. Published on behalf of United Nations Environment Programme and the World Health Organization. (UNEP/WHO).

Bierhuize, J.F.H., and E.E. Prepas. 1985. **Relationship between nutrients, dominant ions and phytoplankton standing crop in prairie saline lakes**. Can. J. Fish. Aquat. Sci., 42: 1588-1594.

Buller, H. 1996. Towards sustainable water management: **Land Use Policy**, v. 13, no. 4, p. 289-302.

Babbitt, H.E., and J. Doland. 1949. **Water Supply Engineering** McGraw-Hill p.388**.**

Baron, J. S., N. L. Poff, P. L. Angermeier, C. N. Dahm, P. H. Gleick, N. G. Hairston, A. D. Steinman. 2002. **Meeting ecological and societal needs for freshwater**. Ecological Applications, 12(5), 1247-1260.

Black, P. E. 1997. Watershed functions. **Journal of the American Water Resources Association**, 33(1), 1-11.

Boyacioglu, H and M. N. Alpaslan. 2008. Total maximum daily load (TMDL) based sustainable basin growth and management strategy. **Environmental Monitoring and Assessment** 146, 411-421.

Bingham, S. 2006. U.K. Environmental Agency**, Water River Quality an overview**. Internet publication.

Botkin and Keller. 2005. **Environmental science, Earth as a living planet.** Fifth edition. Department of ecology, evolution, and marine biology university of California, santa Barbara.

Brinkman, S.F. 2009. **Chronic Toxicity of Ammonia to Early Life Stage Rainbow Trout**. Transactions of the American Fisheries Society 138:433–440.

Baver, L.D. 1968. **Soil Physics.** John Wiley and Sons, Inc., New Yorkk, 489 p.

Baver, L.D., W.H. Gardner. 1972. **Soil Physics**. John Wiley and Sons, Inc.,New York,498 p.

Clair, N., P. L. Sawyer, F. P. Gene. 2003. **Chemistry for Environmental Engineering and Science** (5th edition). New York: McGraw-Hill. ISBN 0-07-248066-1.

Costanza, R. 1997. **The Value of the World's Ecosystem Services and Natural Capital. Nature**, 387, 253-260.

Chen, D. J., J. Lu, S. F. Yuan, S.Q. Jin and Y. N. Shen. 2006. **Spatial and temporal variations of water quality** in Cao-E River of eastern China. J. Environ. Sci. 18:680–688.

Chunkao, K., N. Tangtham, S. Boonyawat, and W. Niyom. 1981. 15-Year Summary "**Mountainous Research Projec**t". Department of Conservation, Faculty of Forestry, Kasetsart University, Thailand.

Chunkao, K. 2001. **Environmental Science**. Bangkok: Kasetsart University. Bangkok, Thailand.

Chunkao, K. 2008, **Principles of Watershed Management**. Kasetsart University Publisher, Kasetsart University, Bangkok, Thailand.

Chunkao, K. 2010. **Environmental Science. 8th edition**, Kasetsart University Publisher, Kasetsart University, Bangkok, Thailand.

Chunkao, K., C. Nimpee, and K. Duangmal. 2012. **The King's initiative using water Hyacinth to remove heavy metals and plant nutrients from wastewater through Bueng Makkasan** in Bangkok, Thailand. Ecological Engineering, 39:40-52.

Cazelles, B., D. Fontvieilli, and N.P. Chav. 1991. Self purification in a lotic ecosystem: **a model of dissolved organic carbon and benthic microorganism dynamics**. Ecological Modelling, 58:91-117.

Doyle, B, and J. Erickson. 2006. **Closing the door on the fecal coliform assay**. Microbe 1:162-163. ISSN 1558-7460.

DOPC. 2010. Annual Report **on Existing Pollution** in Thailand. Department of Pollution Control,Ministry of Natural Resources and Environment, Thailand.

-------. 2013. **Surface Water Quality Standard**. Department of Pollution Control, Ministry of Natural Resources and Environment, Thailand.

Dowd, B. M., D. Press, and L.M. Huertos. 2008. **Agricultural non-point source water pollution policy**: The case of California's Central Coast. Agr. Ecosyst. Environ. 128:151–161.

Dwight, R. H., J. S. Caplan, M. V. Brinks, S. N. Catlin, G. Buescher, and J. C Semenza. 2011. **Influence of variable precipitation on coastal water quality in southern California**. Water Environment Research: A Research Publication of the Water Environment Federation, 83(12), 2121-2130.

Diersing, N. 2009. **Water quality frequently asked question**. Florida Brooks National Marine Sanctuary, Key West, FL.

Elshorbagy, A., R. S. V. Teegavarapu, and L. Ormsbee. 2005. **Total maximum daily load (TMDL) approach to surface water quality management**: Concepts, issues, and applications. Canadian Journal of Civil Engineering, 32, 442-448.

EPA, 1986. Quality Criteria for Water, **US Environmental Protection Agency**, Wash. D.C. EPA 440/5-86-001.

Edwards, A. C., Y. Cook, R. Smart, and A.J. Wade. 2000. **Concentrations of nitrogen and phosphorus in streams draining the mixed land use** Dee catchment, northeast Scotland. J. Appl. Ecol. 37:159–170.

Eckenfelder, M. 2003. Water Quality**, Ambient Water Quality Guidelines for Chloride** Overview Report, Assistant Deputy Minister. Water, Land and air Protection. Canadian Cataloguing in Publication Data, Nagpal, N.K.

Hogan, C.M. 2010. **Water pollution Encyclopedia of Earth**. National Council on Science and the Environment, Washington, DC.

Howarth, R. W., A. Sharpley, and D. Walker. 2002. Sources of nutrient pollution to coastal waters in the United States: **implications for achieving coastal water quality goals**. Estuaries. 25:656–676.

HAII. 2013. **Phetchburi watershed information.** Hydro and Agro Information institute, Royal Irrigation Department, Ministry of Agriculture and Cooperative, Thailand.

Harrington, W., A. J. Krupnick, and H. M. Peskin. 1985. Policies for nonpoint-source water-pollution control. **Journal of Soil and Water Conservation**, 40(1), 27-32.

Jamwal, P., A. K. Mittal, and J. Mouchel. 2011. **Point and non-point microbial source pollution**: A case study of Delhi. Physics and Chemistry of the Earth, 36, 490-499.

Johnson, D. L., S. H. Ambrose, T. J. Bassett, M. L. Bowen, D. E. Crummey, J.S. Isaacson, D. N. Johnson, P. Lamb, M. Saul, and A. E. Winter-Nelson. 1997. **Meaning**. **Journal of Environmental Quality of environmental terms.** 26: 581-589s

Kebede, E., J. Gan, and Z. Gebeyehu. 2003. **Non-Point Source Pollution and Land Use Pattern Linkage**: A Watershed Approach. Journal of the Alabama Academy of Science, 74(3/4), 197-209.

Kailasam, M. and S. Sivakami. 2004. **Effect of thermal effluent discharge on benthic fauna off Tuticorin bay**, south east coast of India. Indian Journal of Marine Sciences. 33 (2): 194-201.

Kraus, J. K., T. S. Schmidt, F. B. Wanty, R. E. Zuelling, and R. E. Wolf. 2014, **Cross-ecosystem impacts of stream pollution reduce resource and contaminant flux to riparian food webs**. Ecological Application, 24:236-243.

Kerr, J. 2002. Watershed development, environmental services, and poverty alleviation in India, World Development, **Vol.30**, No.8, 1387-1400.

Linsley, R. K., M. A. Kohler and J. L. H. Paulhus. 1988. **Hydrology for Engineers**. McGraw-Hill Book Company, London.

Linsley, R. K and J. B. Franzini. 1972**. Water-Resources Engineering** McGraw-Hill ISBN 0-07-037959-9 pp.454-456

LDD. 2011. Report **on the land use in Phetchaburi province.** Land Development Department, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

LERD. 1999. **Technology for Community Garbage Disposal and Wastewater Treatment by Aquatic Plants**. The King's Initiative Laem Phak Bia Environment Studies, Research and Development Project at Laem Phak Bia sub- district, Ban Laem district, Phetchaburi province, Thailand.

-----. 2000. **Science for Garbage Disposal and Wastewater Treatment Towards the King's Initiative Project**. Technical Papers for 10-Year LERD Seminar, Organized by Chaipatana Foundation during 24-25 August 2000 at Kasetsart University, Bangkok, Thailand.

-----. 2010. **Water Quality of Phetchaburi River**. The King’s Loyally Initiated Laem Phak Bia Environment Research and Development Project, Laem Phak Bia sub-district, Ban Laem district, Phetchaburi province, Bangkok, Thailand.

-----. 2011. Annual Report on **The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project** (LERD). Laem Phak Bia sub-district, Ban Laem district, Phetchaburi province, Thailand. (serial numbers in the years of 2005, 2006, 2007, 2008, 2009, and 2011).

-----. 2012. **The King's Initiative Laem Phak Bia sub-district**, Ban Laem distruct, Phetchaburi province, Thailand.

Loomis, J., P. Kent, L. Strange, K. Fausch, and A. Covich. 2000. **Measuring the total Economic Value of Restoring Ecosystem Services in an Impaired River Basin:** Results from a Contingent Valuation Survey. Ecological Economics, 33(1), 103-117.

Liu, W., D. Chen and W. Dong-mei. 2009. **Spatial impact of organic matters from point sources on stream water quality**. Mine Science and Technology, 19:256-261.

Mosley, L., S. Sarabjeet and B. Albersberg. 2004. **Water quality monitoring in Pacific Island countries**. Handbook for water quality managers & laboratories, Public Health officers, water engineers and suppliers, Environmental Protection Agencies and all those organizations involved in water quality monitoring (1st Edition).

Mangimbulude, J.C., N.M. van Stroalen, W.F.M. Rolina. 2012. **Microbial nitrogen transformation potential in surface run-off leachate from a tropical landfill**. Waste Management, 32:77-87.

Mathews, R., and B. Richter. 2007. **Application of the Indicators of Hydrologic Alteration software in environmental flow-setting**. Journal of the American Water Resources Association (JAWRA) 43(6): 1400-1413)

National Environmental Management Act, 1998 **(Act No.107 of 1998) and National Water Act,** 1998 (Act No.36 of 1998) in South Africa.

Noble, R.T., D.F. Moore, M.K. Leecaster, C.D. McGee, and S.B. Weisberg. 2003. **Comparison of total coliform, fecal coliform, and Enterococcus bacterial indicator response for ocean recreational water quality testing**. Water Research. 37: 1637-1643.

Nadia, M. A. 2006. **Study on effluents from selected sugar mills in Pakistan**: Potential environmental, health, and economic consequences of an excessive pollution load: Sustainable Development Policy Institute. Islamabad, Pakistan.

Ometo, J. P. H. B., L. A. Martinelli, M.V. Ballester, A. Gessner, A. V. Krusche, L.R. Victoria and M. Williams. 2000. **Effects of land use on water chemistry and macro-invertebrates into streams of the Piracicaba River basin**, southeast Brazil. Fresh water Biol. 44:327–337.

Pereira, H.C. 1973. **Land use and water resources in temperate and tropical climates**. London, Cambridge University Press.

Paerl, H. W., L. M. Valdes, A.R. Joyner, M.F. Piehler and M.E. Lebo. 2004. **Solving problems resulting from solutions**: evolution of a dual nutrient management strategy for the eutrophying Neuse River Estuary, North Carolina. Environ. Sci. Technol. 38:3068–3073.

Penha-Lopes, G., P. Torres, S. Cannicci, L. Narciso, J. Paula. 2011. **Monitoring anthopogenic sewage pollution on mangrove creeks in Southern Mozambique**: A test of Palaemenconcinnus Dana, 1852 (Palaemonidae) as a biological indicator. Environmental Pollution, 159:636-645.

Petersen, M. M. 1999. **A natural approach to watershed planning, restoration and management**. Water Science and Technology, 39(12), 347-352.

Postel, S. L., and B. H. Thompson. 2005. Watershed protection, **Capturing the benefits of nature's water supply services**. Natural Resources Form, 29, 98-108.

Postel, S., and B. Richter. 2003. Rivers for Life: **Managing Water for People and Nature. Island Press**, Washington, D.C.

Pink, D. H., and L. West. 2006. **Investing in tomorrow liquid gold, world water day, a billion of people worldwide lack safe drinking water**.

Rand, G. M., S.R. Petrocelli. 1985. **Fundamentals of aquatic toxicology: Methods and applications**. Washington: Hemisphere Publishing. ISBN 0-89116-382-4.

Ribbe, L., P. Delgado, E. Salgado and W. A. Flugel. 2008. **Nitrate pollution of surface water induced by agricultural non-point pollution in the Pocochay watershed**, Chile. Desalination. 226:13–20.

Robinson, H.D., And P.J. Maris. 1985. **The Treatment of Leachate from Domestic Waste Sites**. Journal of Water Pollution, 57:41-50.

Rakthai, S. 2012. **Ecosystem Services Value of the Phetchaburi River**, Ph.D. Thesis, Graduate School, Karsetsart University, Bangkok, Thailand, 312 p.

Srigate, J. 2009. **Effects of Community Activities to Water Quality in Phetchaburi River**, Phetchaburi Province. M.S Thesis, Graduate School, Kasetsart University, Thailand.

Swaine, M. D., J. Adomako, G. Ameka, K. A. A. Ston, and M. Cheek. 2006. **Forest river plants and water quality in Ghana**. Aquat. Bot. 85:299–308.

Siegel, L. P. E. 2007. **Hazard Identification for Human and Ecological Effects of Sodium Chloride Road Salt**. State of New Hampshire. Department of Environmental Services, Water Division. Watershed Management Bureau.

Spellman, F.R. and J. Drinan. 2000. **The drinking water handbook**. Lancaster, Pa. Technomic Pub. Co.

Simachaya, W. 2000. **Water Quality Management in Thailand**. Chief of inland water quality sub-division, water quality management division, Pollution Control Department, Thailand.

Tong, S., and W. Chen. 2002. **Modeling the Relationship Between Land Use and Surface Water Quality**. Journal of Environmental Management, 66, 377-393.

Tecle, A., P.F. Ffolliott, J.M.B. Baker, L.F. DeBano, D.G. Neary and G.J. Gottfried. 2003. **Future outlook of watershed management.** Journal of Arizona-Nevada Academy of Science, v. 35, no. 1, p. 81-87.

Tchobanoglous, G. and E.D. Schroeder.1985.**Water Quality**, Addison Wesley, New York.

Tariq, M., M. Ali, and Z. Shah. 2006. **Characteristics of industrial effluents and their possible impacts on quality of underground water**; Soil Science Society of Pakistan Department of Soil & Environmental Sciences, NWFP Agricultural University, Peshawar

Tanji, Y., R. Sakai, K. Miyanaga, and H. Unno. 2006. **Estimation of the self-purification capacity of biofilm formed in domestic sewer pipes**. Biochemical Engineering Journal, 31:96-101.

U.S. EPA. 1998. **Water Pollution Control:** 25 years of Progress and Challenges for the New Millennium. Office of Wastewater. EPA 833-F-98-003.

US Environmental Protection Agency (EPA), 1999. **Update Of Ambient Water Quality Criteria For Ammonia**. EPA-822-R-99-014.

U.S. EPA. 2003b. Monitoring, Assessment and Reporting Guidelines. **Wetlands, Oceans, & Watersheds**.

Valipour, A., V.K. Raman, V.S. Ghole. 2009. **A new approach in wetland systems for domestic wastewater treatment using Phragmite sp**. Ecological Engineering, 35:1797-1803.

Vagnetti, R., P. Miana, M. Fablis and B. Pavoni. 2003. **Self-purification ability of a resurgence stream**.Chemosphere, 52:1781-1795.

Wani, S.P., T.K. Sreedevi, T.S.V. Reddy, B. Venkateswarlu and C.S. Prasad. 2008. **Community watersheds for improved livelihoods through consortium approach in drought prone rainfed areas**. Journal of Hydrological Research and Development. 23:5577.

Wahla, I.H., and M.B. Kirkham. 2008. **Heavy metal displacement in salt-water-irrigated soil during phytoremediation.** Environmental Pollution, LERD. 2010.The King's Loyally Initiated Laem Phak Bia Environment Research and Development Project: Water Quality of the Phetchaburi River.Bangkok, 89 p.155:271-283.

Wang, L.K., D. Vielkind and M.H. Wang. 1978. **Mathematical Models of Dissolved Oxygen Concentration in Fresh Water**. Ecological Modelling, 5:115-123.

Wang, M., J. Zhang, Z. Tu, X. Gao, and W. Wang. 2010. **Maintenance of estuarine water quality by mangroves occuts during flood periods**: A case study of a subtropical mangrove wetland. Marine pollution Bulletin, 60:2154-2160.

WHO. 2004. Consensus of the Meeting: **Nutrient minerals in drinking-water and the potential health consequences of long-term consumption of demineralised and altered mineral content drinking-waters**. Rolling Revision of the WHO Guidelines for Drinking-Water Quality).

Wang, X. 2001. **Integrating Water-Quality Management and Land-Use Planning in a Watershed Context.** Journal of Environmental Management, 61, 25-36.

Wilber, C. G. 1969. **The Biological Aspects of Water Pollution**. Springfield IL: Charles C Thomas.

Weber, S., and K. Duffy. 2007. **Effects of Total Dissolved Solids on Aquatic Organisms**: A Review of Literature and Recommendation for Salmonid Species. Technical Services, 1235 Schodack Landing Road, Schodack Landing, NY 12156 2 Department of Chemistry and Biochemistry, University of Alaska Fairbanks Fairbanks,

Wang, X. L., Y. L. Lu, J.Y. Han, G.Z. He, and T.Y. Wang. 2007. **Identification of anthropogenic influences on water quality of rivers** in Taihu watershed. J. Environ. Sci. 19:475–481.

Xian, G., M. Crane, and J. Su. 2007. **An Analysis of Urban Development and its Environmental Impact on the Tampa Bay Watershed**. Journal of Environmental Management, 85, 965-976.

Xu, H., L.Z. Yang, G.M. Zhao, J.G. Jiao, S.X. Yin, and Z.P. Liu. 2009. **Anthropogenic impact on surface water quality in Taihu Lake region**, China. Pedosphere. 19:765–778.

Ye, L., Q. H. Cai, R.Q. Liu, and M. Cao. 2009. **The influence of topography and land use on water quality of Xiangxi River in Three Gorge Reservoir region**. Environ. Geol. 58:937–942.

Zamzow, K. 2009. **Impacts Of Exploration On Water Chemistry And Adequacy Of Baseline Water Characterization At The Pebble Prospect**. Paper prepared for The Nature Conservancy, Anchorage, AK.

Zhang, X. D., G.H. Huang, and X.H. Nie. 2009. **Optimal decision schemes for agricultural water quality management planning with imprecise objective**. Agr. Water Manage. 96:1723–1731.

APPENDIX

Appendix Table 1 Average of water quality indicators (SW1) 2006-2013

Time	Average of water quality parameter (SW1)									
	Tem	pH	DO	BOD	TDS	EC	NO3-N	NH3-N	FCB	TCB
	°C		mg/L	mg/L	mg/L	µS/cm	mg/L	mg/L	MPN/100 ml	MPN/100 ml
2006	27.1	7.3	5.6	1.4	80	120	0.24	0.1	118	1,514
2007	27.9	7.4	6.9	1.7	72	107	0.77	0.15	546	3,268
2008	27.4	7.7	6.8	1.8	56	98	3.88	0.41	353	1,323
2009	27.4	7.8	7.2	2.4	77	118	1.45	0.61	125	1,627
2010	28.9	7.3	6.8	2.9	104	156	0.77	0.12	479	2,196
2011	29.2	7.5	5.5	1.9	92	145	0.77	0.06	209	2,276
2012	29	7.7	5.6	1.8	81	122	0.60	0.04	1,358	8,869
2013	28.9	7.4	7.0	2.3	91	135	0.64	0.07	750	5,663

Appendix Table 2 Average of water quality indicators (SW2) 2006-2013

Time	Average of water quality parameter (SW2)									
	Tem	pH	DO	BOD	TDS	EC	NO3-N	NH3-N	FCB	TCB
	°C		mg/l	mg/l	mg/l	µS/cm	mg/l	mg/l	MPN/100 ml	MPN/100 ml
2006	28	7.3	5.6	1.7	93	139	0.2	0.03	1,954	34,439
2007	29.4	7.3	5.3	2.5	87	129	0.8	0.12	693	5,192
2008	28.8	7.7	5.1	1.9	77	134	3.83	0.39	1,130	11,700
2009	28.7	7.5	6.0	2.1	87	133	1.29	0.50	698	6,491
2010	29.3	7.1	5.6	3.2	115	172	0.75	0.13	625	4,000
2011	29.7	7.3	4.9	1.9	101	154	0.76	0.06	2,102	12,853
2012	29.7	7.5	4.7	1.5	95	143	0.58	0.05	809	6,806
2013	29.4	7.5	6.2	1.8	99	147	0.58	0.05	800	8,013

Appendix Table 3 Average of water quality indicators (SW3) 2006-2013

Time	Average of water quality parameter (SW3)									
	Tem °C	pH	DO mg/l	BOD mg/l	TDS mg/l	EC µS/cm	NO3-N mg/l	NH3-N mg/l	FCB MPN/100 ml	TCB MPN/100 ml
2006	28.1	7.2	4.9	1.5	103	154	0.23	0.07	308	9,858
2007	29.3	7.4	5.1	1.8	109	162	0.82	0.13	3,877	22,533
2008	28.3	7.7	5.0	1.8	79	139	4.40	0.34	1,468	11,650
2009	29.2	7.4	6.1	2.2	91	139	1.20	0.43	865	14,658
2010	29.6	7.2	5.8	3.5	116	174	0.76	0.17	1,230	8,075
2011	29.7	7.2	4.9	1.8	104	150	0.75	0.08	1,728	11,367
2012	30	7.5	5.0	1.7	97	147	0.57	0.08	804	12,662
2013	29.6	7.5	6.2	2.5	101	150	0.57	0.04	771	21,663

Appendix Table 4 Average of water quality indicators (SW4) 2006-2013

Time	Average of water quality parameter (SW4)									
	Tem °C	pH	DO mg/l	BOD mg/l	TDS mg/l	EC μS/cm	NO3-N mg/l	NH3-N mg/l	FCB MPN/100 ml	TCB MPN/100 ml
2006	28.3	7.5	5.5	1.4	110	164	0.21	0.1	529	18,941
2007	29.8	7.5	5.4	2.2	119	177	0.82	0.13	5,698	53,993
2008	28.9	7.8	5.3	2.0	82	139	4,18	0.25	1,306	8,367
2009	29.6	7.4	6.8	1.9	93	143	1.10	0.31	1,263	13,666
2010	29.8	7.2	6.5	3.0	117	174	0.81	0.11	583	6,325
2011	29.9	7.3	5.3	2.1	109	163	0.75	0.09	2,719	21,450
2012	30.2	7.6	5.5	2.2	99	149	0.58	0.09	698	19,915
2013	29.7	7.6	6.4	2.1	101	151	0.57	0.07	1,089	20,600

Appendix Table 5 Average of water quality indicators (SW5) 2006-2013

Time	Average of water quality parameter (SW5)									
	Tem °C	pH	DO mg/l	BOD mg/l	TDS mg/l	EC µS/cm	NO3-N mg/l	NH3-N mg/l	FCB MPN/100 ml	TCB MPN/100 ml
2006	28.8	7.4	5.8	1.5	112	167	0.2	0.15	4,461	33,308
2007	30	7.6	5.5	2.2	118	177	0.86	0.21	5,665	39,892
2008	29.5	7.8	5.8	2.2	84	147	4.00	0.26	2,911	33,075
2009	29.9	7.4	7.4	2.4	94	145	1.06	0.47	1,243	7,819
2010	30	7.2	6.8	3.8	116	174	0.83	0.13	1,298	7,775
2011	30	7.5	5.8	2.1	110	167	0.72	0.14	3,993	34,208
2012	30.4	7.8	5.8	2.2	100	153	0.56	0.11	763	12,744
2013	29.9	7.4	6.8	2.2	103	154	0.55	0.06	785	18,063

Appendix Table 6 Average of water quality indicators (SW6) 2006-2013

Time	Average of water quality parameter (SW6)									
	Tem °C	pH	DO mg/l	BOD mg/l	TDS mg/l	EC µS/cm	NO3-N mg/l	NH3-N mg/l	FCB MPN/100 ml	TCB MPN/100 ml
2006	28.7	7.4	5.8	1.5	113	168	0.2	0.18	1,269	39,994
2007	29.8	7.4	4.3	2.2	11	166	0.85	0.34	6,817	61,258
2008	29.8	7.8	5.3	2.0	119	155	4.64	0.39	2,697	13,675
2009	30.1	7.6	7.7	2.5	96	147	1.13	0.46	1,945	20,161
2010	30	7.5	6.6	3.3	117	176	0.82	0.13	4,534	20,833
2011	30	7.7	6.1	2.1	111	169	0.71	0.15	3,330	26,642
2012	30.7	7.8	5.7	1.7	102	155	0.57	0.10	2,988	34,237
2013	30.2	7.6	6.5	2.0	105	156	0.55	0.07	989	33,400

Appendix Table 7 Average of water quality indicators (SW7) 2006-2013

Time	Average of water quality parameter (SW7)									
	Tem	pH	DO	BOD	TDS	EC	NO3-N	NH3-N	FCB	TCB
	°C		mg/l	mg/l	mg/l	µS/cm	mg/l	mg/l	MPN/100 ml	MPN/100 ml
2006	28.9	7.4	4.3	1.7	2,897	4,324	0.23	0.19	2,277	16,771
2007	30.3	7.3	4.5	2.6	3,666	5,471	0.77	0.22	1,673	28,775
2008	29.7	7.4	3.5	2.5	3,935	6,687	4.71	0.35	2,684	6,316
2009	30	7.1	4.7	3.5	7,861	9,896	15.63	0.68	2,533	33,000
2010	30.3	7.0	4.2	4.8	6,760	8,535	8.04	0.50	1,452	16,125
2011	30.1	7.2	4.0	3.4	5,492	6,968	10.27	0.16	2,763	15,401
2012	30.9	7.4	3.5	2.7	3,739	5,042	8.93	0.20	415	12,031
2013	30.4	7.5	4.6	2.6	2,561	3,704	5.05	0.21	5,751	28,325

Appendix Table 8 Average of water quality indicators (SW8) in 2006-2013

Time	Average of water quality parameter (SW8)									
	Tem °C	pH	DO mg/l	BOD mg/l	TDS mg/l	EC µS/cm	NO3-N mg/l	NH3-N mg/l	FCB MPN/100 ml	TCB MPN/100 ml
2006	28.8	7.4	3.8	3.3	5,896	8,800	0.32	0.22	604	21,792
2007	29.8	7.3	3.3	2.7	3,401	5,076	1.06	0.44	2,663	23,808
2008	29.9	7.5	2.6	2.8	5,932	8,780	4.29	0.50	1,420	11,062
2009	30.3	6.9	4.1	4.3	13,315	16,612	30.12	0.99	2,669	21,069
2010	30.4	7.0	3.8	4.9	10,683	15,266	14.38	0.70	1,183	13,158
2011	30.2	7.2	3.1	3.8	7,495	11,371	12.99	0.25	4,472	33,520
2012	31.1	7.4	2.9	3.6	7,576	10,181	15.70	0.22	2,060	23,357
2013	30.9	7.5	3.6	4.6	5,454	7,994	10.59	0.31	616	10,129

Appendix Table 9 Rainfall of Kaeng Krachan reservoir station 2004-2013

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
2004	38.4	2.6	0.0	93.4	0.0	79.7	43.3	20.8	105.1	137.2	1.2	0.0	521.7
2005	1.1	0.0	144.7	115.5	200.7	45.5	113.5	60.8	166.3	383.5	6.7	59.2	1,297.5
2006	5.3	25.1	97.1	111.7	280.2	184.3	120.2	26.6	351.3	210.1	51.5	6.8	1,470.2
2007	11.6	0.0	14.7	61.6	357.1	154.9	188.2	197.8	144.0	116.0	53.8	0.0	1,299.7
2008	0.0	29.2	5.3	14.7	94.7	33.3	102.7	220.7	199.1	338.0	6.6	0.0	1,044.3
2009	0.0	9.5	75.9	25.4	376.7	59.1	81.9	65.3	126.2	199.8	37.7	0.0	1,057.5
2010	18.5	53.0	100.8	124.4	83.1	106.2	120.4	112.4	191.0	257.3	5.0	13.3	1,185.4
2011	0.6	15.6	97.0	41.5	199.9	84.7	105.3	70.7	198.8	208.9	4.0	1.4	1,028.4
2012	41.9	0.0	60.0	188.3	108.8	62.2	120.4	48.8	163.9	134.7	168.5	0.0	1,097.5
2013	1.4	0.0	22.8	45.3	54.2	129.0	251.6	59.3	193.0	338.6	258.4		1,353.6
Mean	11.9	13.5	61.8	82.2	175.5	93.9	124.8	88.3	183.9	232.4	59.3	9.0	1,136.5

Appendix Table 10 Monthly water use of Phetchaburi river in 2002

Time	Kaeng krachan riservoir		Inflow of Phetchaburi river		Water use for agriculture	
	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)
January	15.00	40,176,000	7.73	20,704,032	6.18	37,256,544
February	24.64	59,609,088	9.42	22,788,864	18.47	41,226,624
March	23.54	63,049,536	10.12	27,105,408	19.89	45,506,016
April	30.00	77,760,000	9.34	24,209,280	31.17	71,760,384
May	28.70	76,870,080	9.42	25,230,538	31.44	72,543,168
June	30.00	77,760,000	11.15	28,911,168	32.46	84,125,952
July	31.45	84,235,680	17.96	46,552,320	31.71	84,932,064
August	61.29	164,159,136	30.20	80,887,680	34.69	92,913,696
September	90.66	234,990,720	62.68	162,466,560	32.66	84,654,720
October	68.7	184,006,080	49.62	132,902,208	37.98	101,725,632
November	30.16	78,174,720	9.04	23,431,680	34.24	88,750,080
December	12.09	32,381,856	9.60	25,230,538	9.22	24,694,848
Total	37.19	1,173,172,896	19.69	620,420,276	26.68	830,089,728

Appendix Table 11 Monthly water use of Phetchaburi river in 2003

Time	Kaeng krachan riservoir		Inflow of Phetchaburi river		Water use for agriculture	
	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)
January	13.88	35,863,992	6.99	18,722,016	6.62	17,731,008
February	22.14	63,904,896	7.84	18,966,528	16.57	40,086,144
March	30.00	80,352,000	9.35	25,043,040	21.02	54,631,780
April	33.33	86,391,360	7.55	19,569,600	28.96	75,064,320
May	29.19	78,191,998	9.42	25,230,528	28.23	75,611,232
June	25.00	64,800,000	7.52	19,491,840	25.05	64,929,600
July	21.61	57,880,224	11.37	30,453,408	18.13	48,559,392
August	34.67	92,860,128	14.9	39,908,160	28.86	77,298,624
September	16.67	43,208,640	6.14	15,914,880	28.4	73,612,800
October	22.74	60,906,816	29.74	79,655,616	29.73	79,628,832
November	24.33	63,063,360	40.41	104,742,720	32.86	85,173,120
December	14.19	38,006,496	11.33	30,346,272	9.88	26,462,592
Total	23.98	765,429,910	13.55	428,044,608	22.86	718,789,444

Appendix Table 12 Monthly water use of Phetchaburi river in 2004

Time	Kaeng krachan riservoir		Inflow of Phetchaburi river		Water use for agriculture	
	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)
January	10.16	27,212,544	16.65	44,595,360	6.66	17,838,144
February	31.21	78,199,776	6.44	16,136,064	29.45	73,789,920
March	32.90	88,128,000	7.20	19,284,480	32.08	85,923,072
April	41.50	107,568,000	9.06	23,483,520	36.43	94,426,560
May	25.81	69,129,504	9.02	24,159,168	29.00	77,673,600
June	39.83	103,239,360	44.99	116,614,080	16.09	41,705,280
July	65.81	176,265,504	47.51	127,250,784	32.68	87,530,112
August	64.84	173,667,456	44.71	119,751,264	33.91	90,824,544
September	48.17	124,856,640	35.45	91,886,400	27.94	72,420,480
October	20.00	53,568,000	17.82	47,729,088	25.90	69,370,560
November	29.84	77,345,280	5.04	13,063,680	32.23	83,540,160
December	11.93	31,953,312	5.95	15,936,480	9.73	26,060,832
Total	35.17	1,111,133,376	20.82	659,890,368	26.01	821,103,264

Appendix Table 13 Monthly water use of Phetchaburi river in 2005

Time	Kaeng krachan riservoir		Inflow of Phetchaburi river		Water use for agriculture	
	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)
January	10.16	27,216,000	6.17	16,536,960	8.31	22,320,576
February	15.53	37,580,000	8.22	19,908,288	11.28	27,333,548
March	10.96	29,376,000	7.96	21,325,248	8.05	21,582,720
April	14.33	37,152,000	7.05	18,275,328	12.57	32,648,832
May	12.41	33,264,000	7.55	20,238,336	13.78	36,956,736
June	11.83	30,672,000	5.69	14,758,848	14.55	37,761,120
July	27.74	74,304,000	5.34	14,319,936	29.66	79,503,552
August	30.32	81,216,052	6.42	17,211,666	28.13	75,376,870
September	27.83	72,144,000	5.42	14,046,912	32.44	84,092,256
October	9.03	24,192,000	58.88	157,711,104	22.57	60,460,992
November	10.83	28,080,000	13.69	35,480,160	18.24	47,295,360
December	8.39	22,464,000	9.10	24,364,800	5.21	13,960,512
Total	15.78	497,660,052	11.79	374,177,586	17.07	539,293,074

Appendix Table 14 Monthly water use of Phetchaburi river in 2006

Time	Kaeng krachan riservoir		Inflow of Phetchaburi river		Water use for agriculture	
	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)
January	13.87	37,152,000	6.04	16,179,264	10.10	28,500,768
February	25.00	60,480,000	8.66	20,950,272	17.64	42,722,352
March	33.87	90,720,000	7.19	19,266,336	31.53	84,481,056
April	33.00	85,536,000	5.54	14,371,776	34.30	88,947,936
May	29.83	79,920,000	12.22	32,743,008	35.46	95,040,000
June	25.50	66,096,000	24.78	64,248,768	22.13	57,392,064
July	97.63	261,493,920	89.44	239,575,104	32.63	87,450,624
August	112.04	300,105,216	84.44	226,179,648	51.02	136,684,800
September	109.25	283,199,328	78.05	202,312,512	44.54	115,502,112
October	64.77	173,491,200	50.85	136,199,232	41.77	111,913,920
November	35.16	91,152,000	12.76	33,082,560	33.56	87,045,408
December	10.16	27,224,640	4.94	13,257,216	9.91	26,576,280
Total	49.17	1,556,570,304	32.08	1,018,365,696	30.38	962,257,320

Appendix Table 15 Monthly water use of Phetchaburi river in 2007

Time	Kaeng krachan riservoir		Inflow of Phetchaburi river		Water use for agriculture	
	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)
January	8.38	22,464,000	6.94	18,592,416	4.68	12,578,976
February	23.92	57,888,000	5.23	12,650,688	19.62	47,520,000
March	33.38	89,424,000	5.56	14,896,224	28.25	76,238,496
April	36.50	94,608,000	7.20	18,665,352	32.81	85,043,520
May	4.52	12,096,000	16.76	44,880,480	12.79	33,973,344
June	8.33	21,600,000	12.17	31,561,056	17.91	46,443,456
July	21.93	58,752,000	49.66	133,024,896	10.33	27,662,688
August	85.16	228,096,000	64.11	171,706,176	39.99	107,104,896
September	47.00	121,824,000	8.10	20,983,968	36.06	93,477,024
October	57.90	155,088,000	66.69	172,862,208	36.18	93,789,792
November	30.81	82,512,000	13.28	34,426,944	31.07	80,534,304
December	12.90	34,560,000	6.08	15,755,040	12.20	31,611,168
Total	30.89	978,912,000	21.81	690,005,448	23.49	735,977,664

Appendix Table 16 Monthly water use of Phetchaburi river in 2008

Time	Kaeng krachan riservoir		Inflow of Phetchaburi river		Water use for agriculture	
	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)
January	12.90	34,560,000	6.04	15,657,408	9.1	23,581,152
February	27.90	74,736,000	6.61	17,133,984	28.64	74,226,240
March	36.61	98,064,000	6.53	16,917,120	37.59	97,441,920
April	35.16	94,176,000	6.76	17,521,920	36.59	94,841,280
May	33.55	89,856,000	7.46	19,323,360	35.95	93,174,624
June	21.94	58,752,000	8.22	21,296,736	22.63	58,655,232
July	19.03	50,976,000	6.31	16,356,384	17.07	44,254,080
August	46.45	124,416,000	14.87	38,539,584	37.09	96,146,784
September	31.45	84,240,000	9.90	25,649,568	32.63	84,570,048
October	24.35	65,232,000	17.73	45,962,208	29.91	77,520,672
November	6.97	18,671,040	5.19	13,441,248	21.08	54,649,728
December	11.94	31,968,000	4.40	11,403,072	6.13	15,886,368
Total	25.69	825,647,040	8.33	259,202,592	26.20	814,948,128

Appendix Table 17 Monthly water use of Phetchaburi river in 2009

Time	Kaeng krachan riservoir		Inflow of Phetchaburi river		Water use for agriculture	
	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)
January	14.35	38,448,000	4.99	12,926,304	9.46	24,516,000
February	27.26	73,008,000	4.87	12,614,400	19.81	51,357,024
March	36.45	97,632,000	4.81	12,471,840	31.08	80,552,448
April	38.39	102,816,000	4.62	11,982,816	32.33	83,790,720
May	34.19	91,584,000	5.11	13,248,576	28.71	74,411,136
June	15.16	40,608,000	5.60	14,519,520	14.19	36,789,984
July	21.13	56,592,000	7.09	18,365,184	16.68	43,233,696
August	60.52	162,086,400	34.81	90,237,024	39.66	102,790,080
September	59.68	159,840,000	31.76	82,308,960	40.28	104,397,984
October	27.58	73,872,000	29.69	76,958,208	29.69	76,958,208
November	39.19	104,976,000	11.33	29,365,632	32.10	83,198,844
December	16.61	44,496,000	8.69	22,524,480	10.12	26,221,536
Total	32.54	1,045,958,400	12.78	397,522,944	25.34	788,217,660

Appendix Table 18 Monthly water use of Phetchaburi river in 2010

Time	Kaeng krachan riservoir		Inflow of Phetchaburi river		Water use for agriculture	
	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)
January	10.65	28,512,000	8.46	21,926,592	5.82	15,075,072
February	26.94	72,144,000	19.04	49,354,272	19.04	49,354,272
March	45.48	121,824,000	7.88	20,419,776	31.69	82,143,072
April	46.13	123,552,000	10.78	27,936,576	36.10	93,562,560
May	42.58	114,048,000	9.38	24,306,048	44.37	114,931,008
June	25.16	67,392,000	10.89	28,219,968	26.91	69,756,768
July	11.94	31,968,000	8.10	20,994,336	12.10	31,373,568
August	29.19	78,192,000	18.14	47,026,656	24.98	64,743,840
September	20.48	54,864,000	18.13	46,995,552	26.05	67,517,280
October	0.89	2,376,000	22.70	58,825,440	16.02	41,527,728
November	22.42	60,048,000	7.96	20,640,960	28.16	72,984,672
December	13.71	36720000	6.20	16,060,896	11.16	28,913,760
Total	24.63	791,640,000	12.30	382,707,072	23.53	731,883,600

Appendix Table 19 Monthly water use of Phetchaburi river in 2011

Time	Kaeng krachan riservoir		Inflow of Phetchaburi river		Water use for agriculture	
	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)
January	10.16	27,216,000	6.99	18,107,712	5.52	14,309,568
February	11.45	30,672,000	7.16	18,552,672	6.51	16,882,560
March	8.87	23,760,000	9.89	25,645,248	6.73	17,443,296
April	11.13	29,808,000	7.90	20,486,304	7.94	20,584,800
May	8.06	21,600,000	10.69	27,702,432	8.45	21,892,032
June	7.77	20,822,400	10.16	26,331,264	12.34	31,983,552
July	23.55	63,072,000	8.88	23,018,688	16.68	43,239,744
August	49.35	132,192,000	27.88	72,258,912	30.04	77,872,320
September	42.90	114,912,000	20.34	52,732,512	24.77	64,202,112
October	30.97	82,944,000	25.94	67,226,112	25.89	67,112,928
November	41.77	111,888,000	10.11	26,199,072	27.07	70,177,536
December	16.13	43,200,000	10.15	26,309,664	11.81	30,602,880
Total	21.84	702,086,400	13.01	404,570,592	15.31	476,303,328

Appendix Table 20 Monthly water use of Phetchaburi river in 2012

Time	Kaeng krachan riservoir		Inflow of Phetchaburi river		Water use for agriculture	
	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)	Q (m^3/s)	Volume (m^3)
January	16.13	43,200,000	9.38	24,303,456	23.68	61,389,928
February	37.26	99,792,000	9.58	24,824,448	27.12	70,290,720
March	42.10	112,752,000	9.25	23,987,232	32.00	82,932,768
April	40.81	109,296,000	8.27	21,439,296	31.57	81,820,800
May	25.00	66,960,000	9.93	25,750,656	22.32	57,846,700
June	117.74	315,360,000	10.00	25,913,088	6.28	16,266,528
July	17.90	47,952,000	9.47	24,535,872	10.89	28,214,432
August	43.87	117,504,000	16.70	43,297,632	26.88	69,684,192
September	39.68	106,272,000	16.73	43,352,064	29.60	76,711,104
October	36.35	97,372,800	23.72	61,484,832	30.78	79,790,400
November	26.45	70,848,000	12.98	33,642,432	22.55	58,448,737
December	6.29	16,848,000	9.68	25,097,472	2.01	5,208,192
Total	37.47	1,204,156,800	12.14	353,325,024	22.14	688,604,501

Appendix Table 21 Monthly water inflow to Kaeng Krachan reservoir 2002-2012

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2002	21.40	14.80	31.40	16.20	96.10	60.20	127.10	326.90	261.60	136.40	61.90	120.70	1,274.70
2003	17.1	20.2	30.6	24.4	45.1	37.9	136.2	121.3	120.1	516.9	41.68	25.31	1,136.79
2004	16.61	19.01	10.54	16.79	123.43	116.17	85.03	177.45	89.41	54.01	27.23	12.99	748.67
2005	12.645	11.54	7.76	16.1	16.96	28.81	132.18	85.6	273.08	150.15	44.7	23.53	803.06
2006	23.59	13.21	14.81	23.78	95.1	74.93	519.95	296.4	180.53	173.52	49.36	23.94	1,489.12
2007	20.04	13.73	25.6	42.19	40.15	28.56	255.98	189.23	185.1	176.14	59.7	26.28	1,062.70
2008	20.25	17.8	17.4	38.49	63.89	48.27	76.86	123.64	167.14	101.97	60.68	29.87	766.26
2009	22.93	27.38	50.21	47.89	67.07	134.93	156.48	307.1	152.21	175	65.38	30.4	1,236.98
2010	19.1	24.92	33.85	47.32	43.18	24.51	29.97	63.66	97.07	84.18	36.08	18.61	522.45
2011	10.98	13.98	15.6	25.05	42.35	96.53	314.7	231.24	201.79	151.05	69.95	24.35	1,197.57
2012	34.07	33.61	47	54.85	38.73	81.56	148.129	227.32	177.233	127.81	69.38	25.762	1,065.45
Average	19.73	19.54	25.34	33.69	57.60	67.22	185.55	182.29	164.37	171.07	52.41	24.10	1,002.90

Appendix Table 22 Monthly water outflow Kaeng Krachan reservoir 2002-2013

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2002	40.18	59.61	63.05	77.76	76.87	77.76	84.24	164.16	234.99	184.01	78.17	32.38	1,173.18
2003	35.86	63.90	80.35	86.39	78.19	64.80	57.88	92.86	43.21	60.91	63.06	38.01	765.43
2004	27.21	78.20	88.13	107.57	69.13	103.24	176.27	173.67	124.86	53.57	77.35	31.95	1,111.13
2005	27.22	37.58	29.38	37.15	33.26	30.67	74.30	81.22	72.14	24.19	28.08	22.46	497.66
2006	37.15	60.48	90.72	85.54	79.92	66.10	261.49	300.11	283.20	173.49	91.15	27.22	1,556.57
2007	22.46	57.89	89.42	94.61	12.10	21.60	58.75	228.10	121.82	155.09	82.51	34.56	978.91
2008	34.56	74.74	98.06	94.18	89.86	58.75	50.98	124.42	84.24	65.23	18.67	31.97	825.65
2009	38.45	73.01	97.63	102.82	91.58	40.61	56.59	162.09	159.84	73.87	104.98	44.50	1,045.96
2010	28.51	72.14	121.82	123.55	114.05	67.39	31.97	78.19	54.86	2.38	60.05	36.72	791.64
2011	27.22	30.67	23.76	29.81	21.60	20.82	63.07	132.19	114.91	82.94	111.89	43.20	702.09
2012	43.20	99.79	112.75	109.30	66.96	315.36	47.95	117.50	106.27	97.37	70.85	16.85	1,204.16
2013	27.65	103.85	104.11	114.48	115.78								465.87
Mean	32.47	67.66	83.27	88.60	70.77	78.83	87.59	150.41	127.30	88.46	71.52	32.71	926.52

Appendix Table 23 Monthly water flow from Phetchaburi diversion dam 2002-2013

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2002	20.70	22.79	27.11	24.21	25.23	28.91	46.55	80.89	162.47	132.90	23.43	25.23	620.42
2003	18.72	18.97	25.04	19.57	25.23	19.49	30.45	39.91	15.91	79.66	104.74	30.35	428.04
2004	44.60	16.14	19.28	23.48	24.16	116.61	127.25	119.75	91.89	47.73	13.06	15.94	659.89
2005	16.54	19.91	21.33	18.28	20.24	14.76	14.32	17.21	14.05	157.71	35.48	24.36	374.18
2006	16.18	20.95	19.27	14.37	32.74	64.25	239.58	226.18	202.31	136.20	33.08	13.26	1,018.37
2007	18.59	12.65	14.90	18.67	44.88	31.56	133.02	171.71	20.98	172.86	34.43	15.76	690.01
2008	15.66	17.13	15.66	17.52	19.32	21.30	16.36	38.54	25.65	45.96	13.44	11.40	257.94
2009	12.93	12.61	12.47	11.98	13.25	14.52	18.37	90.24	82.31	76.96	29.37	22.52	397.52
2010	21.93	49.35	20.42	27.94	24.31	28.22	20.99	47.03	47.00	58.83	20.64	16.06	382.71
2011	18.11	18.55	25.65	20.49	27.70	26.33	23.02	72.26	52.73	67.23	26.20	26.31	404.57
2012	24.30	24.82	23.99	21.44	25.75	25.91	24.54	43.30	43.35	61.48	33.64	25.10	377.63
2013	25.95	22.88	28.91	27.40	25.43								130.57
Mean	21.18	21.40	21.17	20.45	25.69	35.62	63.13	86.09	68.97	94.32	33.41	20.57	478.49

Appendix Table 24 Monthly water use to agricultural production 2002-2013

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2002	37.26	29.15	31.26	53.67	54.76	72.46	71.81	69.72	60.77	82.23	66.72	20.09	649.90
2003	17.11	33.12	51.12	69.21	69.51	59.33	37.23	63.69	60.96	62.89	68.17	22.15	614.49
2004	15.11	55.75	68.65	76.85	63.83	37.61	71.86	72.24	51.73	54.77	66.22	21.32	655.94
2005	19.19	22.81	17.77	27.67	34.70	43.19	63.06	61.50	67.03	46.13	33.48	13.22	449.75
2006	26.31	35.23	70.03	72.26	75.82	50.91	64.40	97.70	82.34	84.12	65.87	22.11	747.10
2007	11.17	39.75	61.70	68.78	29.02	38.35	21.43	75.64	67.66	65.61	61.10	27.28	567.49
2008	23.24	49.60	77.87	76.44	74.21	49.31	38.61	76.07	63.96	60.51	42.39	14.11	646.32
2009	23.53	38.55	64.89	71.84	61.95	31.88	43.23	79.61	76.94	59.93	67.93	23.00	643.28
2010	13.06	40.39	70.51	83.13	104.37	64.95	31.37	56.55	57.51	35.27	57.54	22.89	637.54
2011	12.99	14.56	13.60	17.89	19.71	28.78	334.53	59.99	56.72	59.58	61.21	29.78	709.34
2012	43.07	58.82	61.07	62.71	48.99	16.26	28.21	62.79	65.74	66.05	44.71	0.52	558.94
2013	7.37	57.52	68.86	70.95	74.01								278.71
Mean	20.78	39.60	54.78	62.62	59.24	44.82	73.25	70.50	64.67	61.55	57.76	19.68	596.57

Appendix Table 25 Monthly water consumption for Hua Hin district 2002-2013

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2002	-	12.07	14.25	18.09	17.78	11.66	13.12	23.19	23.90	19.50	22.03	4.61	180.22
2003	0.62	6.97	3.51	5.86	6.11	5.60	11.33	13.61	12.65	16.74	17.00	4.31	104.30
2004	2.73	18.04	17.28	17.57	13.85	4.10	15.67	18.59	20.68	14.60	17.31	4.74	165.16
2005	3.13	4.52	3.81	4.98	2.26	3.57	16.45	13.88	17.06	14.33	13.81	0.74	98.51
2006	2.19	7.49	14.45	16.68	19.22	6.48	23.05	38.98	33.16	27.80	21.17	4.46	215.14
2007	1.40	7.77	14.54	16.26	4.96	8.08	6.23	31.46	25.81	28.17	19.43	4.33	168.44
2008	0.34	24.62	19.57	18.40	18.96	9.34	5.64	20.07	20.61	17.01	12.26	1.78	168.59
2009	0.98	12.81	15.66	11.94	12.46	4.91	-	23.17	27.45	17.03	15.26	3.22	144.89
2010	2.01	8.96	11.63	10.43	10.56	4.81	-	8.19	10.00	6.25	15.44	6.02	94.29
2011	1.32	2.32	3.84	2.69	2.18	3.20	8.70	17.87	7.48	7.52	8.96	0.81	66.90
2012	1.83	11.47	21.85	19.11	8.85	-	-	6.89	10.96	13.73	13.73	-	108.43
2013	0.49	13.10	18.87	19.09	19.65								71.20
Mean	1.42	10.84	13.27	13.43	11.40	5.61	9.11	19.63	19.07	16.61	16.04	3.18	132.17

Appendix Table 26 Relationship of water flow and water quality indicators.

Indicators	Q(m3/s)	Station of sample water point along Phetchaburi river							
		SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
Tempe	22.4	29.6	29.6	30.0	29.6	29.8	29.8	30.2	30.2
(°C)	100	28.1	27.5	27.8	27.8	27.8	27.9	28.8	28.7
	377	27.7	27.6	27.6	25.0	26.4	27.2	26.7	27.5
pH	22.4	7.6	7.5	7.4	7.4	7.6	7.7	7.3	7.3
	100	7.3	7.8	7.9	7.9	7.9	7.8	7.8	8.0
	377	7.9	7.9	7.9	7.7	7.6	7.8	7.6	7.7
DO	22.4	3.2	2.9	2.9	2.8	2.5	2.6	1.1	0.2
(mg/L)	100	6.5	6.0	5.2	5.5	5.2	5.2	5.2	4.4
	377	5.8	5.7	5.9	6.3	6.1	5.7	5.7	5.1
BOD	22.4	1.5	2.0	1.8	2.7	1.8	2.7	3.8	4.1
(mg/L)	100	2.9	4.9	2.5	2.2	2.4	2.9	1.6	4.4
	377	4.0	3.0	2.9	3.6	2.9	2.6	3.3	2.3
TDS	22.4	121	129	121	120	121	122	566	2,544
(mg/L)	100	160	169	177	168	168	170	170	215
	377	144	135	134	136	136	134	143	205

Appendix Table 26 (Continued)

Indicators	Q(m3/s)	Station of sample water point along Phetchaburi river							
		SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
EC	22.4	184	195	183	183	184	186	858	3,180
(µS/cm.)	100	239	253	253	251	250	252	255	320
	377	214	201	199	206	203	200	213	306
NO3-N	22.4	0.62	0.70	0.68	0.67	0.67	0.70	0.59	5.30
(mg/L)	100	1.20	1.33	1.36	1.35	1.35	1.37	1.37	1.40
	377	0.67	0.73	0.76	0.74	0.74	0.82	0.78	0.72
NH3-N	22.4	0.04	0.05	0.06	0.08	0.12	0.13	0.13	0.22
(mg/L)	100	0	0	0	0	0	0	0	0
	377	0	0	0	0	0	0	0	0
TCB	22.4	9,200	5,400	16,000	9,200	16,000	9,200	9,200	5,400
(MPN/100mL)	100	5,400	9,200	16,000	3,500	2,800	5,400	9,200	5,400
	377	92,000	9,200	54,000	92,000	16,000	5,400	9,200	3,500
FCB	22.4	1,800	1,700	2,800	330	2,200	230	270	340
(MPN/100mL)	100	1,100	1,100	1,800	270	170	330	940	330
	377	17,000	1,400	17,000	11,000	2,200	700	790	490

CURRICULUM VITAE

NAME : Mr. Soulivanh VORAVONG

BIRTH DATE : May 18, 1977

BIRTH PLACE : XEINGKHUANG Province, LAO PDR

EDUCATION :

YEAR	INSTITUTE	DEGREE/DIPLOMA
2005	NUOL	B.Sc (Engineering)
2014	Karsetsart Univ	M.S.(Environment)

POSITION/TITLE : Head of cooperation and plan sector.

WORK PLACE : Department of Irrigation, Ministry of Agriculture and Forestry, Lao PDR.

SCHOLARSHIP/AWARDS : SEARCA Scholarship 2012-2014