CHAPTER II

LITERATURE REVIEWS

Reviews of Literature

2.1 Watershed Ecosystem

Watershed is defined as (1) a dividing ridge between the drainage areas (2) the region or area drained by a particular body of water (3) a crucial dividing point (Hewlett and Nutter, 1969). Watershed is a basin unit of water management. It is necessary to understand how hydrology and ecological processes interact to sustain ecosystem functioning and the provision of ecosystem goods and services (EPA, 1996 and Strange *et al.*, 1999). It will be so difficult to place either ecological or social value on alternative watershed management scenarios (Calder, 1999). The watershed management is likely to become so important to human society with regards to high water demand with limited supply (Strange *et al.*, 1999).

Watershed floodplains have historically been favored sites for human habitation because rivers provided a number of environmental goods and services. Watersheds provide water for domestic and agricultural use, fish, fertile soils and possibilities for transport and waste removal (Lorenz *et al.,* 2001). Rivers and streams are complex ecosystems in which many environmental factors vary on different spatial and temporal scales. These variables can range from climate, land use, and geomorphology in the watershed to the physical, chemical and biological characteristic of rivers and streams (Stevenson and Pan, 1999). By the rising population densities, water quality degraded further because of increased discharges of urban sewage, effluents from developing industrial centres and agricultural intensification. The use of river to remove wastes and surpluses has caused a decline in water quality. (Strange *et al.,* 1999). Water quality is also regulated by ecological processes that occur as water moves between the surface and area of subsurface flow (Stanford and Ward, 1988). Nutrient environment of river water can contribute to blooms and die-offs and to decomposition and depletion of dissolved oxygen, reducing water quality and creating unfavorable conditions for other aquatic life. Phytoplankton is a biotic organism and is in virtually all bodies of water. It presents as the most important producer in aquatic ecosystem (Geider and Osborne, 1992). Nitrogen and phosphorus are major cellular components of its organisms. Since the availability of these elements may be less than the biological demand, environmental sources can regulate or limit the productivity of organism in freshwater ecosystems (Wetzel and Likens, 2000). Although these nutrients are very important for photosynthesis, other ecological factors such as dissolved oxygen, light, temperature, pH and salinity are also necessary. The changes of these factors can affect to biomass, phytoplankton and the primary productivity of the aquatic ecosystem. These factors are well known for use as indicators in aquatic ecosystems (Loeb and Spacie, 1994 and Wetzel and Likens, 2000).

Although chemical method can also be used to determine nutrient or toxicant concentration in water samples, these may not accurately reflect biological responses. For example, a chemical analysis of total phosphorus may overestimate the amount of this element that is biologically available to organisms (Skulberg, 1995). Measurement of all physical and chemical factors that could be an important determinant of ecosystem integrity is impractical. Biological indicators respond to alter physical and chemical conditions that may not have been measured. Clearly, biological factors provide an integrated assessment of environment conditions in lotic and lentic water that are spatially and temporally highly variable (Stevenson and Pan, 1999). Biological indicators are important parts of environmental assessments because protection and management of these organisms are the objectives of most programs (Stoermer and Smol, 1999).

Phytoplankton is a group of aquatic organisms and is in virtually all bodies of water such as, blue green algae, green algae, diatom and dinoflagellate. It is photosynthetic and oxygenic autotrophs that are typically smaller and less structurally complex in terms of structure than terrestrial plants (Graham and Wilcox, 2000). Phytoplankton is the most important group of primary producers on earth and on the base line of food webs in aquatic ecosystem. It is dependent on the activities of other microbial organism, which convert organic material in organism into the inorganic nutrients required by producers. The concentration of photosynthetic pigments especially, chlorophyll *a* is used extensively to estimate phytoplankton biomass because it is an important component of pigments in phytoplankton. It is also used as an indicator of eutrophication in both freshwater and marine water ecosystems (OECD, 1982). However, phytoplankton has different and unequal importance in each area of water body (Hoek, Mann and Jahns, 1995). Phytoplankton are also useful laboratory organisms for understanding ecological processes such as succession and responses to disturbance because they are small, grow rapidly, have short generation times, and are easily cultivated under laboratory conditions. The use of phytoplankton assemblages as indicator of water quality has a long tradition (Palmer, 1969), especially in Europe. It is sugguested that they are a good monitoring organism of heavy metals presence and toxicity in waters (Graham and Wilcox, 2000). The widely used phytoplankton biomonitor for freshwater are unicellular green algae, *Selenastrum capricornutum* and *Scenedesmus subspicatus,* and marine diatoms, *Steletonema costatum* and *Phaeodactylum tricornutum* (Graham and Wilcox, 2000).

An ecological approach is an understanding of the interconnectedness of the biogeochemical processes and environment. The changes caused by humans may have ecological effects beyond those intended or foreseen. From this perspective, it is in humanity's self–interest to protect the basic ecological processes that are the processes of life-support system (EPA, 1996; and Strange *et al.,* 1999). Humans can reconsider to protect these processes by having an environmental consciousness. The challenge of the ecological approach was given global scope by the World Commission on Environment and Development by articulating the goal of sustainable development. The idea of sustainable development suggests future generations should enjoy the same opportunities for meaningful and fulfilling lives as the current generation. The concept serves as an umbrella to encourage development of renewable resources and conservation of non-renewable resources (EPA, 1996). The ecological approach is an important key to understand the problem of environmental policy implementation to be the moral education of individuals and institutions to the dimensions of the ecological crisis, changing the climate in which decisions are made, and providing opportunities for individuals and institution to make decisions based on ecological concerns, rather than having those choices limited to alternatives dictated solely by economic criteria (Dudgeon, 2000).

2.2 River Ecosystem

Streams and rivers within their watershed drainage basins are central to surface water ecosystems. Lotic ecosystems are in contrast to ***lentic*** or lake ecosystems. Most lakes are open and have distinct flows into, through, and out of their basins. Throughflows into, termed the ***water renewal rates***, are of ten variable and very slow in lakes but are continuous. The distinction between lakes and running water focuses on the relative residence times of the water. The importance of variable but continuous and rapid throughput of water and materials contained in it is evident in the biology of most organisms inhabiting running waters. When the energy of flowing water is dissipated, as in the transitional zone of reservoirs, the change to lentic characteristics is rapid. Only 0.0001 % of the water of earth occurs in river channels (Miller, 1999). In spite of these low quantities, running waters are of enormous significance to humans and other living organisms not only terrestrial but also aquatic (Miller, 1999). Erosion moves large amounts of dissolved and particulate matters from the land to the sea. Small streams and rivers often flow to lakes and eventually large river systems (Wetzel, 2001).

The phytoplankton community is composed of a diverse assemblage of algae species populations. Many species of river phytoplankton reproduce prolifically in rivers and achieve biomass level. Diatoms usually dominate in the plankton of large rivers along with, particularly in summer, a variety of green algae. Many flagellates, chrysophytes, and cyanobacteria are suppressed where currents are vigorous; these groups can increase in significance in areas where currents are reduced. Successful phytoplankton species in rivers must be adapted, however, to survive frequent fluctuations in irradiance as they are moved by currents erratically through their vertical light filed. Often much of the mixed layer is in effective darkness and entrained cells spend more than half their light hours at light levels insufficient to support net photosynthesis. River phytoplankton generally exhibit fast growth rates and hence tend to be smaller in size than phytoplankton of lakes and reservoir. The generation times of river phytoplankton must be more rapid than the time of displacement downstream.

2.3 Lake Ecosystem

The origin of lake basins and their morphometry are of much more than casual interest in physical, chemical, and biological events within the basins and play a major role in the control of lake's metabolism, within the climatological constraints of its location. The geomorphology of a lake controls the nature of its drainage, the inputs of nutrients to the lake, and the volume of influx in relation to flushing-renewal time. These patterns in turn govern the distribution of dissolved gasses, nutrients, and organisms, so that the entire metabolism of freshwater systems is influenced to varying degrees by the geomorphology of the basin and how it has been modified throughout its subsequent history. Human have created artificial lakes by damming streams for at least 4,000 years (Wetzel, 2001). Only in the last two centuries, however, this activity has become highly significant for the purposes of flood control and the provision of hydropower and water supplies for irrigation and urban consumption population. Reservoirs are being constructed on an unprecedented scale in response to the exponential water demands of humans.

Much of our Limnological understanding originates from natural lake ecosystems. Hundreds of thousands of reservoirs have been created by human activities. These artificial water bodies have been created for the specific purpose of water management. Examples include water storage, flood control, generation of electrical energy, and recreation. Reservoirs differ in significant ways from natural lake ecosystems. Study of reservoir ecosystems indicates many functional similarities between artificial and natural lakes. In order to effectively manage and utilize reservoirs it is important to understand the structural differences between these man-made ecosystems and natural lakes while simultaneously appreciating their functional similarities. Understanding of these structural differences is mandatory for effective management and use of impounded water resources. Failure to recognize basic similarities in metabolic functioning and community interrelationships of the biota will only result in redundancies in reservoir research that can be basically understood from our existing knowledge of processes in natural lakes (Wetzel, 2001). The vertical distribution of phytoplanktonic biomass varies greatly from season to season with shifts in species composition. In the seasonal depth distribution of chlorophyll *a* concentration, corrected for pigment degradation products, values are low in winter and increase in different strata during the period of summer stratification in temperate lake.

Tropical lakes are far less numerous of phytoplankton than temperate lakes and are dominated by lakes of river origin. Greater solar irradiance with reduced annual variations results in higher minimum water temperate. Although smaller thermal discontinuities exist between upper and lower water strata, density differences can be very large and result in high stabilities. The predominantly warm monomictic tropical lakes exhibit great regularity in seasonal mixing, which typically coincides with the hemispheric winter. In many tropical lakes surrounded by extensive, nutrient-buffering wetlands and receiving perennial river inflow, total phytoplanktonic biomass and productivity are often both larger and more constant seasonally than those found in temperate lakes. Phytoplankton communities are no more complex in tropical lakes than in lakes of higher latitudes (Wetzel, 2001).

Nutrient levels are one of the most important determinants of the detailed pattern of species change because the same taxa of algae tend to dominate the changes in lakes of similar trophic status, but phytoplankton varies in lakes of different trophic status (Reynoids, 1980, quoted in Harper, 1992). For example, in oligotrophic lakes desmids i.e. *Staurastrum*, *Cosmarium*, *Staurodesmus*, diatom i.e. *Tabellaria*, *Cyclotella*, *Melosira* and *Rhizosolenia*, chrysophyte i.e. *Dinobryon* were found. In mesotrophic lakes, desmid was found i.e. *Straurastrum* and *Closterium*, diatom i.e. *Cyclotella*, *Stephanodiscus*, *Asterionella*, green algae i.e. *Pediastrum*, *Eudorina*, dinoflagellates i.e. *Peridinium* and *Ceratium*. In eutrophic lakes diatom was found i.e. *Melosira*, *Asteroinella* and *Stephanodiscus*, green algae i.e. *Scenedesmus* and *Eudorina* and blue green algae i.e. *Aphanizomenon*, *Microcystis* and *Anabaena*. However, there were some genus of phytoplankton living in both clean water and polluted water e.g. *Navicula*, *Phormidium*, *Agmenellum*, *Ulothrix*, *Euglena*, *Pinnularia*, *Cyclotella* and *Cladophora* etc. (Palmer, 1997).

In eutrophic lakes, blue green algae (cyanobacteria) such as *Aphanizomenon*, *Anabaena* and *Microcystis* are most common in eutrophic lakes in the warm waters of Summer and Fall. They can survive over Winter as akinetes, sporelike resting stages.

Planktonic blue green algae succeed because they regulate their position in the water column to the depths most favorable for growth. This occurs by a two–step process: (1) production of relatively permanent minute gas vacuoles that give a slight positive buoyancy in starved cells; and (2) photosynthetic production of dense carbohydrate during the day, which acts as ballast to cause sinking. The ballast is used up overnight and the algae float to the surface in the morning to resume the cycle and float near the surface shades out competing algae. Large colonies rise or sink much faster than single filaments and large colonies of blue green algae dominate as the Summer-Fall plankton in eutrophic lakes. A few genera of blue green algae, such as *Aphanizomenon*, can fix dissolved atmospheric N_2 gas. All other algae groups and many blue green lack this ability (Horne and Goldman, 1994).

The need for management of lakes and rivers reflects an inability of the ecosystems to operate in self – sustaining ways because of interference or damage that exceed the capacities of the ecosystem for self–repair (Moss, 1999). Most demands for management are a result of disturbances by human activities. Impediments to successful management include (a) the basic complexity and stochasticity of natural ecosystems which may change or be altered faster than they can be understood and managed; (b) an ecosystem scale required in evaluation of appropriate methods for effective management, a scale that does not lend itself readily to rigors of potential effects; and (c) political impediments, often large, such that if a portion of society should choose to exploit a resource in an unsustainable way, scientific understanding is of little assistance (Wetzel, 2001).

2.4 Watershed management

"An ecosystem has been widely accepted as an important concept in theory but, until recently, not in practice. One reason is that the quick-fix or piecemeal approach so often works well in the short run of political and economic worlds. Thus, timber management has increased the yield of wood, and deer management has increased the number of deer, often to the point where the deer graze down all the tree seedlings! So it is evident that we must now move up the scale to more holistic levels of management in order to avoid what we might call the tyranny of small technologies.

Since the ecosystem is the lowest complete unit in the ecological levels of organization hierarchy (it has all the components, biological and physical, necessary for survival!), it is a logical level around which to organize both theory and practice. Where human are numerous or very active, the environment become so fragmented and cut up into patches and strips that management has to move up to the next level in the hierarchy, i.e., the landscape. The watershed as a landscape-level unit becomes an ideal management focus because it is both a geographic unit, usually with discrete boundaries, and a functional system unit with input and outputs."

(*Eugene P. Odum* in Reimold, 1998)

Watersheds are areas delineated by natural hydrological boundaries and are used to manage water quality and develop solutions to environmental problems. These areas include natural assemblages of natural resources that rely on the type and quantity of water present within the watershed. Over the past several decades, humans concerned with the environment have embraced the notion that one of the most important indicators of the health of our natural resources is the quality of the water. It follows that when the quality of rivers, lakes, streams, ponds, and wetlands is improved and protected, we will have more healthy lands, wildlife, air, and overall environment.

Effective management of watershed depended on a comprehensive human understanding of the components of watersheds and their interactions. The application of ecological principles to watershed planning has recently become one of the most important topics of natural resource management discussions. Traditionally, interest in balanced natural resource (land or water) management has come only after humans have first severely damaged a landscape. To paraphrase the world famous naturalist Aldo Leopold: Humans do not seem to be able to understand a system that they did not build; instead, they seemingly must partially destroy and rebuild the system before its use limitations are understood and appreciated.

Consequently the watershed initiative has evolved beyond the nearly exclusive farm, range land, forest and development focus which characterized its early history. The watershed approach includes the whole urban-rural landscape complex. In many areas of the world, the deteriorating quality of urban and suburban areas threatens the entire economic and social system. Implementing effective management is infinitely more difficult in urban areas than rural areas because of the interconnected social and human aspects of urban areas, and because of the significant difference in monetary value placed on different type of land use (including natural system). Differences in agricultural versus urban land use result was significantly impacts on the quantity and quality of water of the watershed as well as the stability and functions of the lands within the watershed.

The relative stability and function of a watershed are determined by the rate of a water inflow and outflow, materials (substrate), and activity patterns of organisms living within the watershed (Reimold, 1998). In other words, fields, forests, towns, and waters linked together by a stream or river flow interact and consequently are appropriated as one management unit.

The U.S. Environmental Protection Agency (EPA) has endorsed a watershed approach that results in integrated environmental management (EPA, 1996). This initiative involves local community-based consensus building to make environmental management decisions as well as a watershed-based effluent trading strategy which includes environment, economic, and social benefits of such trading. The watershed based planning focuses not on specific chemical constituents of water but on the general suitability of a watershed for recreation, aquatic life, and other uses (Strange *et al.*, 1999). As a result, a number of risk-based management frameworks have evolved.

In recent years, sustaining aquatic ecosystems was considered in many regions in the world. Many researchers were interested in watershed management based on ecosystem management. Schindler (1998) studied the sustaining aquatic ecosystems in Boreal Regions and reported that few boreal waters are managed in a sustainable manner, because cumulative effects of a variety of human activities are not considered. There are important interactions among human activities, requiring that they not be treated in isolation. Ecological sustainability of boreal waters would control the exploitation of all parts of the boreal landscape. Unfortunately, management for sustainability is lacking of the scientific understanding in many countries. In addition, Strange *et al.* (1999) studied the sustaining ecosystem services in Human-dominated watersheds: biohydrology and ecosystem processes in the South

Platte River Basin, North America. The research proposed a framework for predicting ecological consequences of flow manipulation, community, and ecosystem processes. Results indicated the importance of integrating hydrology and biology to predict ecological consequences of flow regime manipulations and the need to apply general flow-restoration principles on a case-by-case basin. Moreover, Fisher *et al.* (2000) studied the relationship of land use practices to surface water quality in the Upper Oconee Watershed of Georgia. The study reported that the analysis of the watershed identified agricultural impacts and areas that should be priorities for the natural resource management to reduce agricultural non-point source pollution. Focusing conservation efforts at these locations may prevent agricultural-urban conflict. However, the data also indicated that municipal sources of nutrients and fecal bacteria must be reduced to make significant progress in the watershed. Lorenz *et al.* (2001) studied the sustainable management of transboundary river basins: a line of reasoning. The report proposed a basis for the management framework (1) indicators that described the complex interactions and processes in rivers; (2) a suit of linked models that predicted the economic, environmental and ecological effects of management measures; (3) an evaluation framework to rank different management alternatives on the basis of three objectives: economic efficiency, spatial in costs and benefits and environmental quality defined the potential of the river and receiving lake. The result of the case study indicated the conflict of economic efficiency in relation to spatial equity and environmental quality.

Bari (2001) studied the effect of land management on soil productivity in a shifting (JHUM) cultivation system: A case study of Talukdarpara Watershed, Bandarban, Bangladesh. The study reported that the shifting (Jhum) cultivation is the main agricultural production system in the Chittagong Hill Tract of Bangladesh. The study was to provide insight into the soil productivity of this system. Talukdarpara, a watershed in Bandarban District, was selected as the study area. The study based on a farm survey and soil analysis. The study also included the farm area of a research station, Soil Conservation and Watershed Management Center (SCWMC), to compare the traditional shifting cultivation practices in the area with the modern soil management practiced on the research farm. Shifting agriculture is sustainable if practices in the traditional way, with 3 - 4 years cropping followed by a 10 - 15 years follow period, during with the natural vegetation is allowed to regenerate. However, during the last 15 - 20 years, pressure on the land has increased, mainly due to the establishment of the Kaptai Reservoir that occupies large areas of fertile agricultural land and a significant increase in population. Consequently, the follow period has been reduced to only 3 - 5 years. This leads to reduced soil fertility and increased susceptibility of the soil to erosion. Under these conditions, shifting cultivation becomes unsustainable and yields level decrease. Soil erosion has also reportedly increased, resulting in further loss of soil fertility and downstream situation.

Results of soil analysis and the farm survey supported the farmers' perceptions on soil fertility degradation and consequent yield decline in the area. The system is more productive and sustainable if the soil is managed using practices such us hedgerow cultivation and terracing. Four important factors were identified that affect the quality of land management, i.e., land user rights, lack of effective research and extension, limited alternative income possibilities, and the lack of marketing for the agricultural produce. Information on the physical and chemical soil properties, their dynamics and their influences on soil fertility in the study area could be used as basis for further investigation and rehabilitation of the degraded agro-ecosystem in the area.

2.5 Watershed Management in Thailand

Before the 1950's, Thailand had a thick forest cover of heterogeneous types. Timbers, particularly teak were the most important export commodity after rice. More than half of the kingdom's area was covered with vast tracts of tropical forests. The people enjoyed superfluous abundance of forest resources. The Royal Forest Department (RFD) was not aware of the rapid depletion of these natural resources which occurred after the 1950's at an uncontrollable rate, causing many of the serious environmental problems faced today. Due to increased population pressure, the forest lands in the catchment areas were rapidly converted into agricultural lands over the last three decades.

After experiencing frequent flash floods in the rainy seasons, severe droughts in the dry seasons and ever decreasing forested lands, the RFD became alarmed by these problems. Four watershed rehabilitation field stations were set up in 1953 under the

Silviculture Division of the RFD. The initial function of these field units was to protect the forest areas from shifting cultivation practiced by nomadic hill tribes. The field units also planted various domestic tree species to test their suitability for rehabilitating the abandoned shifting-cultivated areas.

To cope with the accelerated problems related to water resources, deforestation in catchment areas and siltation in many reservoirs and hydro-electric dams, the Watershed Research Section was established in the Silvilculture Division of the RFD in 1965. The solution of the watershed management related problems were beyond the ability of this small section. Hence, Watershed Management Division (WMD) was established in 1981 in the RFD. Its responsibilities in managing watershed areas are: reforestation of areas abandoned by shifting cultivation, relocation and settlement of permanent villages for nomadic hill tribes, by introducing them to grow cash and perennial crops. The WMD also guards the remaining forest stands in the catchment areas. Farm wood lots, fuel wood plantations and range land management are also being accomplished for the benefit of the hill tribes who are living in watershed areas. This is to slow down the destruction of the remaining forests in the watersheds.

For hydrological purposes, Thailand has an area of about 513,000 km^2. In 1990 the National Water Resources Commission (NWRC) subdivided hydrologically into 25 river basins. The average annual rainfall for all over the country is about 1,700 mm. The total volume of water from the rainfall in all river basins in Thailand is estimated at 800,000 million m^3, of which 75 percent (600,000 million m^3) is lost through evaporation, evapotranspiration and infiltration and the remaining 25 percent (200,000 million m^3) constitutes the runoff that flows in rivers and streams. The population of Thailand is around 60 million. Therefore, the availability of water resources is 3,300 m^3 per person each year which is statistically considered to be highly adequate. The data on surface water resources in Thailand were as shown in Table 2.1.

Table 2.1 Thailand's surface water resources

Regions in Thailand	Catchment areas (km^2)	Average annual rainfall (mm/year)	Amount of rainfall (million m^3)	Amount of runoff (million m^3)
Northern	169,640	1,280	217,140	65,140
Central	30,130	1,270	38,270	7,650
Northeastern	168,840	1,460	246,500	36,680
Eastern	34,280	2,140	73,360	22,000
Western	39,840	1,520	60,560	18,170
Southern	70,140	2,340	164,130	49,240
Total	512,870	-	799,960	198,880

Source: Thai National Committee on Irrigation and Drainage (THAICID)

Thailand's past three decades of sustained and rapid economic development have stimulated a quantum expansion in the demand for water services for power, irrigation and domestic and industrial usage. The government has devoted significant resources to meet this demand, and an approach towards water resources management has emerged, with emphasis on the expansion of access to services-electricity, irrigation and water supply for domestic purposes. This approach has been successful in giving millions of Thai people access to potable drinking water, water to produce cheap and abundant food, and to generate hydroelectricity. However, as water has become increasingly scarce, this approach is no longer appropriate.

In the past, Thailand had paid not much attention to water resources management because water was abundant, anyone could get the required amount of water from rivers, lakes, canals or directly from rainfall. Most of water programs were dedicated to water development during that time. Even when population and economic activities have increased, there was still lack of water resources management practice.

The unclear policy, legal and institutional framework governing basin areas makes it difficult to effectively implement basin management. Inadequate and sometimes conflicting legislation is a problem. Also, there are multiple agencies involved in basin management, and none of them have clear responsibility for basin management and development. Forest cover in the northern river basins has declined from 28% to 18% over the past 25 years, and continues to be under pressure despite a logging ban.

Forest loss is due to the combined effects of illegal logging operations and the increasing population pressures on land resources, the latter fueled by the need to provide food, income and shelter for increasing highland populations. Traditional shifting cultivation rotations have become shorter under the influence of high hilltribe population growth rates, increased competition for land from the lowland Thai communities and the inward migration from neighboring countries. The combined effect of declining land productivity and increasing population results in further forest encroachment, usually on land forms that are unsuitable for cropping activities. The problem has been aggravated by the financial crisis faced by Thailand since July 1997 which has caused large scale urban unemployment. Many of these unemployed workers have returned to their home villages for subsistence support. This has caused increased need to expand the land area under cultivation, and increased forest fires have resulted from the increased land clearing. Loss of forest cover and inappropriate land-use practices have detrimentally affected the hydrology of these basins, and resulted in topsoil erosion, sedimentation of waterways and storage structures, and is also thought to contribute to increased wet season run-off and consequent downstream flooding, and reduced dry season stream flows. Thus, improved management of these upper watersheds is of vital importance. The government now faces a different and more complex set of challenges, comprising both supply and demand. The description of water provision and water demand in the 25 river basins were as shown in Table 2.2.

Table 2.2 Description of water provision and water demand in the 25 river basins of Thailand

Basin No.	Name of River Basins	Catchment Average Area	Runoff (mcm.)	Storage capacity (mcm.)	Irrigation Area (rai)	Water Requirement (MCM./year)				
						Domestic Consumption	Tourism Industry	Ecological Balance	Irrigation Agriculture	Hydropower
1	Salawin	17,920	8,571	24.00	188,948.00	11.96	4.46	1,027.81	616.93	-
2	Mae Khong	57,422	19,362	1,551.00	1,692,333.00	132.57	1.98	1,145.69	4,323.33	-
3	Kok	7,895	5,279	30.00	520,767.00	14.90	0.43	680.00	401.39	-
4	Shi	49,477	8,752	4,256.00	1,863,173.00	195.17	49.62	573.33	3,052.82	2,156.00
5	Mun	69,700	26,655	4,255.00	1,819,785.00	337.88	94.30	956.63	2,628.85	591.30
6	Ping	33,898	7,965	14,107.00	1,942,927.00	75.26	1.00	457.27	2,428.20	3,623.00
7	Wang	10,791	1,104	197.00	472,350.00	20.21	1.00	48.00	487.42	45.00
8	Yom	23,616	3,117	98.00	994,205.00	53.87	0.08	315.36	859.13	-
9	Nan	34,330	9,158	9,619.00	1,780,637.00	66.29	0.32	315.36	2,870.80	2,583.00
10	Chao Phraya	20,125	22,015	33.00	5,731,375.00	1,594.40	646.05	125,000.00	8,768.59	-
11	Sakaekrang	5,191	1,297	162.00	436,410.00	862.00	-	3.35	878.75	-
12	Pasak	16,292	2,820	124.00	661,120.00	72.32	23.28	158.00	927.38	-
13	Thachin	13,682	22,300	416.00	2,385,259.00	94.94	310.25	1,000.00	4,292.11	-
14	Mae Klong	30,837	7,973	26,690.00	3,400,000.00	20.34	-	1,577.00	4,323.33	4,670.00
15	Prachinburi	10,481	5,192	57.00	733,862.00	8.08	2.78	377.00	838.32	-
16	Bang Pakong	7,978	3,713	74.00	1,353,263.00	14.18	9.05	946.00	2,243.60	1.94
17	Tonglesap	4,150	6,266	96.00	123,720.00	12.60	-	9.80	197.00	-
18	East Coast	13,830	11,115	596.00	427,000.00	129.10	83.50	74.70	578.46	79.00
19	Phetchaburi	5,603	1,400	750.00	562,688.00	14.30	2.90	67.00	1,110.00	693.00
20	Prachuap Khiri Khan Coast	6,745	1,420	537.00	327,015.00	18.00	2.97	39.10	1,383.00	-
21	South East Coast	26,353	23,270	5.00	1,780,481.00	56.40	8.70	161.70	1,129.10	2,577.00
22	Ta Pi	12,225	12,513	5,865.00	245,970.00	25.90	10.00	3,085.20	144.60	2,596.00
23	Songkhla Lake	8,495	4,896	28.00	905,550.00	56.45	37.50	312.00	2,994.70	-
24	Pattani	3,858	2,738	1,420.00	337,878.00	31.20	22.44	670.00	441.11	1,152.00
25	South West Coast	21,172	25,540	20.00	339,273.00	53.20	18.90	74.80	253.00	-

Source: Thai National Committee on Irrigation and Drainage (THAICID)

Evolution of water management

Water management in Thailand has evolved with time. Three periods can be distinguished, each with its own focus (TDRI 1990), as follows:

1283 to 1857 - *Managing people to suit water conditions*: Water management was accomplished by moving people closer to or away from water sources as necessary. People were moved to areas with enough water for rice production and away from flood-prone areas. This could be done easily because there was plenty of land and seasonal relocation was compatible with military activity and wars.

1857 to the present-*Supply-side management*: The country was relatively free from war and the stable production of rice for consumption and export was feasible. Early in this period, water was viewed as belonging to the king, who distributed it on an as-needed basis through a government agency-hence the name Royal Irrigation Department. Most of the early water management effort was canal digging (for example, the Rangsit canal network) and water regulation for agriculture and transportation. As the population increased, the later efforts concentrated on building reservoirs and expanding irrigation areas. During this period, water was still so plentiful that wastewater was sufficiently diluted and hence was not perceived as an issue. During this period, irrigation and drainage were the main components of management.

From now to 2025 - ***Demand-side management***: At present Thailand is entering a third period, in which population and economic development pressures will dictate the nature of water management. In contrast to the first and second periods, water management will be characterized by transport of water from distant sources to where the people and activities are, by control and regulation of wastewater, and by efforts to conserve water.

In some respects, sophistication in water management will probably reach the current level of control of the mining industry. Mining concessions (for water) must clarify the rights and liabilities of users and are submitted to a sophisticated tax system. As more activities compete for the relatively constant amount of water, water gradually becomes like precious or; users will have to pay for it as well as for wastewater discharge. Water rights and allocation plans will have to be set up to minimize and mediate conflicts.

Thailand produces sufficient food for its domestic consumption. Most of the Thai people live in lowlands along the rivers. Some of these ethnic people and more than half a million people of nomadic hill tribes live in the mountains areas and earn their livelihood through shifting cultivation, and try growing and selling vegetables all through the year. These people also take water from upstream to irrigate their lands in dry seasons. This has affected the farmers living in the lowland areas. Disproportionate use of water resources has resulted in conflicts and disputes over water supply and its consumption among farmers living in upstream and in downstream areas. Many of the upstream watersheds have deteriorated by clearing of forests and by cultivation of subsistence crops by hill tribes. The Government of Thailand has urgently carried out special programs to rehabilitate these watersheds through reforestation. Many watershed programs and projects are currently run by the government for improving the living condition of hill tribes. Improved agricultural practices, protection of forests from encroachment and shifting cultivation, afforestation of degraded areas and eradication of optimum–growing practices, are the key programs implemented in the upland watersheds. Based on land capability and land use, all the watersheds of the Kingdom have been classified into five groups. Farmers heavily rely on water resources for cultivation and livelihood, but they do not assume any responsibility for watershed management. In the past, therefore, people's participation in watershed management was minimal. However, the government at present has changed its policy to ensure people's participation in all the watershed management programs.

Main features of The current, The Eighth National Economic and Social Development Plan (1997 - 2001)

The larger the population, the higher the demand for water, but also the greater the pressure on land, so much so that watershed encroachment has become so prevalent it has led to severe water degradation. The rapid industrialization cum urbanization in and around Bangkok and some provincial towns has worsened the degradation to the point that water there has become a health hazard.

Besides the taxing problems of water quality and availability, management of water resources is hampered by the inefficient enforcement of public regulations, and the top-down, centralized approach results in poor performance. Except for the small-scale projects, which are planned from the local level upward, all medium-sized and large-scale projects are mooted by the central planning authorities based on hydrological and technical information but precious little information on the social side: local needs are investigated only at the project initiation stage. Moreover, there is little coordination among related agencies, which in a few cases results in overlapping project areas. The involvement of the local population is very limited and often causes misunderstandings between line agencies and local groups. These phenomena occur because there is no comprehensive plan of water management of the national river basins.

The first attempt to determine systematically a water resources management plan and guidelines was the study of the potential development of water resources in the 25 river basins of Thailand. The study started in 1993 and was completed in 1994. It covered data collection and preliminary analysis of the potential of each river basin to meet the demand for water for the period 1994 to 2006. However, it concentrated on the potential development of each of the 25 river basins with very little linkage to adjacent upstream and downstream basins.

In order to provide policymakers with a comprehensive river management strategy, the Chao Phraya river basin, which comprises eight sub-basins, was selected as a test case. The entire Chao Phraya river basin is the focus of the country's growth since it covers about 30 percent of the total land area with 27 million people-half of the total population at the time and accounts for most of the country's agricultural production, industrialization and urbanization.

The main objective of the study was to formulate a comprehensive water management strategy for river basins, by integrating the needs of long-term planning and the requirements of short-term real-time operations, basin development and environmental protection, water quality and quantity, and surface and groundwater development. This meant integrating institutional, policy, legal and technical measures in order to provide a coherent framework of basin planning and management to guide the systematic development, management and protection of a basin's water resources to meet the demands of socio-economic and population growth in the basin.

Thus, in the Eighth National Economic and Social Development Plan, the main strategy was to establish the systematic management of water resources, especially at river basin level, including the provision of clean drinking water and the supervision of water quality, pollution control and drainage. This strategy includes the following guidelines (Sethaputra, *et a*l.):

1) Organizing supervisory and coordinating mechanisms for the development of water resources at both national and river basin levels in order to ensure consistency and continuity in the work of all related agencies.

2) With the participation of all parties concerned, setting up appropriate systems at various levels for the allocation of water resources between the various types of water consumer, based on the principles of necessity, priority and fairness.

3) Collecting fees for raw water from industrial and agricultural producers and from domestic consumers. The price structure for domestic consumption and industrial usage will be adjusted to properly reflect the real cost of procurement, production, distribution and wastewater treatment.

4) Improving the transmission and allocation systems for both irrigation and domestic usage in communities, in order to minimize wastage of clean water through leaks.

5) Conducting public information campaigns to promote thrifty and effective use of water, encourage the use of water-saving devices and the re-use of cooling water and treated wastewater in some industrial activities.

Priority policy issues in The Ninth National Economic and Social Development Plan (2002 - 2006)

Halfway through the implementation of the Eighth National Plan, the application of the basin approach to water resources management and the establishment of a river basin authority are in the early stage, while water resources management problems are worsening. Therefore, in the Ninth National Economic and Social Development Plan, priority will be given to the following issues (Sethaputra, *et al*.):

1) Shifting from the supply-side approach to the demand-side strategy. In Thailand, the supply-side approach has dominated the development and management of water resources for more than three decades. With new water-related problems arising, serious consideration should be given to the demand-side approach. Instead of focusing on investment for additional water supplies, the demand management option will concentrate on the organizational and institutional aspects in order to reduce costs while promoting sustainability and environmental conservation.

2) A comprehensive overall basin water management strategy will be substituted to the project-by-project approach. This strategy will be formulated by integrating institutional, policy, legal and technical measures, and will seek to provide guidance for the systematic development, management and protection of a basin's water resources in order to meet the increasing demands of socio-economic and population growth in the basin area.

3) Water should be recognized as a tradable commodity, since it has an economic value in all its competing uses. Therefore, incentives, regulations, permit restrictions, and penalties that will help guide and convince the people to use water efficiently and equitably will be established. Meanwhile, innovations in water-saving technology will also be encouraged.

4) Economic instruments should be considered for the alleviation of protracted water crises. The regulations supporting these economic instruments

should be clear and acceptable to all groups of water users. Effective and realistic cost-recovery mechanisms should be adopted and implemented. This would require considerable public awareness and education. Whether full cost recovery or recovery of operational cost is pursued should depend on water usage and local conditions.

5) The government will try to set up the institutional framework of water administration with users' participation by transforming its strategy and operating style in order to give the opportunity to stakeholders, especially local people, to participate in water resources management, such as: announcing to the public all the projects that affect people living in a given area, and allowing representatives from the operating area to participate in the decisions that affect them.

6) The private sector should be encouraged to play a more important role in water resources management, especially concerning wastewater in urban areas.

People living in the affected watershed areas are mostly poor subsistence farmer's time is mostly spent on finding food to feed their families. The idea of conserving watersheds has not yet occurred to them. Today, many NGO's and private institutions are actively supporting the Government run watershed management programs. Thus, several hundred hectares of abandoned and shifting cultivated areas have been planted and rehabilitated by the joint efforts of these groups and the government. Today, many programs have been designed and launched to encourage people's participation in watershed management. The national vision statement for Thailand is shown below (Pfotenhauer, 1994).

> *"By the year 2025, Thailand will have sufficient water of good quality for all users through efficient management and an organizational and legal system that will ensure equitable and sustainable use of water resources, with due consideration for the quality of life and the participation of all stakeholders."*

2.6 Reviews of the Study

2.6.1 Reviews of the watershed management

Thailand is an agricultural country in Southeast Asia and has many natural water resources. Because of a lack of public awareness of its magnitude and importance, freshwater resources are polluted. Changes in the hydrological cycle caused by climatic conditions or anthropogenic activities can have a large impact on the water level and hydrochemistry of freshwater ecosystem. These changes can also modify the species composition in the freshwater ecosystem.

The previous project of watershed management in Thailand on the environmental consideration of watershed management plan was carried out at the Lam Nam Oon Watershed in the Northeast. The original project feasibility was based on the development of irrigated agriculture for approximately 170,000 rai and reduction of downstream flood damage. After the Lam Nam Oon irrigation project was broadened in 1977 into integrated rural development project include an integrate program of community development, agricultural research and extension, provision of farm inputs, farm product marketing, health and family planning services, and adult education, the six-year USAID project yielded the increasing in the quality of life of poor farming families. The integrated project involves participation of over 12 Royal Thai Government agencies as well as local and provincial authorities (RID, 1977). The general purpose was to make an example site of environmental aspects which might be taken into consideration while preparing and implementing a watershed management plan. The plan was concluded the environmental controlling factors on watershed and effects of watershed management on the environment in the area.

In 1979, Mae Chaem Watershed Development Project was carried out within the Highland Area Development Committee by the Royal Thai Government that was supposed by USAID (1979). Mae Chaem Watershed is the subwatershed of the Mae Ping Basin in Chiangmai Province. The major problems related to the extreme variability in land use, especially agricultural activities without conversation caused sediment to increase in the water and was thus carried along downstream, and this reduced the potential of agricultural productivity. The overall objective of project was increasing the living standards of the people with minimum averse effects on the environment. The integrated watershed management activities comprised of conversation of soil productivity and water quality through erosion control, development of water supplies for use in the watershed within the constraint of maintaining water supply and water qualities on downstream area, monitoring and correction the watershed conditions to minimize diverse effects.

Beyond the watershed developments, the projects tended to regard people only as part of the problem rather than as part of the whole watershed. Even the concept of the watershed management approaches promoted 1980s may yet have three functions, namely protective, productive and assessable. Therefore, many watersheds in Thailand have been or will soon be environmentally degrade to the point that without environmental management, the population will not able to support themselves even at the subsistence level.

Since 1989, when the watershed management plan in Thailand was set up by the government, only some watersheds have been under the management plans such as, Ping, Wang, Yom, Nan and Chao Praya. Only a few areas in some watersheds are succeeded by their individual plans (OEPP, 1998). Most of the studies in watershed management were carried out within the highland area. In 1998, there was a study of the low-hill watershed development plan in Huai Jo Watershed, San Sai District, Chiangmai Province. The study reported that the optimal development plan of the Huai Jo Low-hill Watershed is reallocating the existing land use to the fruit trees under the criteria of land capability and storage water in the reservoir for a good quality of life as a main objective.

2.6.1.1 River and Stream projects

Diverse investigations in rivers and streams have been carried out throughout the country. They includes how physical factors affect chemical conditions and how human impacts influence on quality of water. The development of simulation models to be used in area classification and prediction are also addressed. Lastly, phytoplankton studies in some rivers as well as their relationship with nutrients are stated.

Somjit (1997) studied influence of geology and weathering in Bangpakong Watershed on total cations in the river and reported that chemical composition of surface waters is influenced by cation-exchange process during the end of dry season while they were largely controlled by weathering of silicate rocks, such as albite, and partly by cation exchange process during the end of rainy season. Influence of geology and weathering on chemical composition of surface waters in Bangpakong watershed area was likely to be most significant during the rainy season in which weathering and transport were at maximum. Furthermore, Siwasen (1997) studied the effects of land uses on physical water quality of Linthin Watershed, Kanchanaburi Province during the period of May 1993 to April 1994 and reported that different land uses caused significantly different water qualities especially electrical conductivity. Residential and agricultural areas induced average electrical conductivity higher than shifting cultivated area, natural area and animal raising area.

In addition, Kongritti (1997) studied the effect of watershed classification on potential surface flow of three representative watersheds: case study at Maetaeng, Chern and Klong Yan Watersheds and reported that the annual streamflow was the highest in Klong Yan and followed by Maetaeng Watershed and Chern Watershed respectively. In Chern Watershed, a total coliform bacterium in agriculture-forest was the highest whereas agriculture-forest plantation area, natural forest and agriculture-forest-communities were lower respectively. In Khlong Yan Watershed, total coliform bacteria and fecal coliform bacteria of agriculture were the highest and agriculture-forest, agriculture-forest-communities and natural forest were lower respectively. In comparison of the bacterial water-quality between 3 watersheds, total coliform bacteria and fecal coliform bacteria in natural forest and agriculture-forest of Mae Taeng Watershed were the highest while they were lowest in Khlong Yan.

Klomjek (1997) studied the roles of land use and land cover changes on nutrient contents in stream water of managing representative watersheds of Mae Taeng, Chern and Khlong Yan watershed during February 1995 to February 1996. The study reported that the water quality, especially nutrients indicated the activity or land use and land cover changes, since these activities produced translocation or accumulation of nutrients of water resources specifically, in risky area to soil erosion in slope complex and natural forest.

Effect of land use and land cover changes on physical water qualities in streamflow was with representative watersheds of Maetaeng, Choen and Klongyan (Lohkam, 1998) It was reported that the major land use showed permanent agricultural patterns and human settlement on headwater sources. The Klongyan Watershed representation of South showed the major land use destroyed some conservation forest area for planting rubber plantation as the economic vegetation on headwater sources. The physical water qualities of all three representative watersheds were not greater than the maximum standard of natural water quality in Thailand. The physical water qualities of Klongyan Watershed were classified as the best followed by Maetaeng Watershed and Choen Watershed respectively. The physical water qualities would be changed due to human activities in the watershed.

Tojinda (1997) developed an analysis of mathematical models for the evaluation of Mae Yom Watersheds critical state from land use ratio. The model testing showed that the acceptable determination coefficient was 64.57% under consideration of subwatershed basis and 56.06% as calculated under the basis of random sampling grids in the whole watershed. According to total sampling of 9,565 grids, the evaluation of Mae Yom Watersheds critical state was found the average value of 2.304 which indicated as slight to moderate values of classified as warning to risky states. In addition, the mathematical model would rather be applicable in area basis than random grid sampling. Besides, it could be applied to predict the disturbance indication of each grid which was the basic criteria for land use planning for future prospect.

Yuvanondha (1997) studied the impact of forest depletion on peak flow and dry period flow in Nan Basin. The study based on the nineteen-year of observed data gathered during 1973 to 1993 by Royal Irrigation Department and Meteorological Department. Forest area maps that were published by Royal Forest Department were also employed to detect land-use change during the mentioned period. The study indicated that forest area decreased from 92 percent to 56 percent for the upper part, from 90 percent to 43 percent for the middle part, from 71 percent to 36 percent for the lower part of Nan basin. Land-use change in terms of forest area depletion showed insignificant influence on peak flow and dry period flow in the upper, middle and lower Nan basin. Regarding factors for prediction peak flow and dry period flow at the upper, middle and lower Nan basin, streamflow of the previous day (1 day), and 1 day and 3 day antecedent rainfall influenced on peak flow significantly. Dry period rainfall had insignificant effect on dry flow due to very low amount of rainfall occurring in the period. Niratsayakul (1999) studied GIS application for the evaluation of water and land resources potential on Sakae Krung Basin, Thailand by using data interpreted from satellite images in 1990 and 1997 and soil property and suitability for agricultural practices as recommended by Department of Land Development. The study reported that there was an extension of agriculture land into the forest area that had inappropriate slope for agricultural practices. The expansion of agricultural land increased the total amount of water consumption within the basin since an agricultural sector normally consumes water more than any other sectors. The evaluation of water discharge quantity using simple linear regression of dry season rainfall-runoff relationship on Mae Wong Sub Basin founded that the amount of discharge was less than that of consumption which, in turn, was causing inadequate supplies of water.

Simachaya (1999) used geographic information systems and the WASP5 simulation model as the integrated approaches to water quality management This study in Tha Chin river Basin reported that the most effective water quality management scenarios simulated by the 70% of current pollution loads reduction throughout the entire basin, which was relatively simple and inexpensive technologies. But strict measures are taken to address the current water pollution levels. The simulation for the year 2014 demonstrated that water quality problem in the river will have increased dramatically by that time, with low dissolved oxygen concentrations reaching as far as approximately 100 km upstream from the river mouth. Unhakanjnkij (1999) studied mathematical model for water resources management in Chanthaburi River Basin using Visual Basic based on statistical methods, namely, Adaptive Filtering, Lag-One Markov Process, Winters Method and Decomposition model. The study reported that none of the flow forecasting models using Adaptive Filtering, Lag-One Markov Process, Winters Method or Decomposition method gave good results when they were compared to observed data. The multiple regression analysis method was then selected to forecast the flow. It was found that the total amount of water demand would be increased to 501.60 MCM per year in the future and the future reservoir storage of 179.872 MCM would be sufficient.

Phytoplankton, as primary producers are very important in an aquatic food web. Their abundance and composition in aquatic ecosystems are regulated by abiotic mechanisms such as nutrients related to physical-chemical variability and biotic, trophic interaction (Sin *et al.*, 1999). However, the relationship between phytoplankton dynamics and environmental change is still poorly understood in many regions of the world (Miretzky *et al.*, 2002). Seasonal succession of phytoplankton has been studied mainly in lakes of the Temperate Zone and in a few tropical lakes (Miretzky *et al.*, 2002), but relatively little information is yet available for lakes in Asia (Dudgeon, 2000).

For the study of phytoplankton in Thailand, there were many researches of phytoplankton in both of the lotic and lentic ecosystem such as, Keolek (1989) studied the use of algae as water qualities indicator of Chi River Basin and reported that, the algae in Chi River Basin was identified as having 41 genera comprising of Divisions; Chrysophyta, Chlorophyta, Cyanophyta, Euglenophyta and Pyrrophyta. In Chi River Basin, however, the algae were the same genera but varied in accordance with watershed classification. The study concluded that the use of algae as an indicator of watershed qualities highly related to the classification of watershed class, except for the third watershed class which was not correlated because of the abuse of land use. Rakkittham (1996) studied investigation on species composition and abundance of plankton in Mae Klong River, Kanchanaburi Province from April 1992 to February 1993 and reported that there were 6 phyla of phytoplankton, and 60 genera with mostly green algae. Three phyla of zooplankton were found including 14 genera and 4 taxa with mostly rotifer. Most of physico-chemical water properties in Mae Klong River were at optimum range for plankton population growth. The relationships between abundance of various plankton families and water qualities were found that pH had relation on Family Desmidiaceae at highly significant ($p > 0.01$).

Thientaworn (1997) studied the relationships between phytoplankton and water quality in the Maeklong River from December 1994 to November 1995. A total of 66 genera in 6 phyla of phytoplankton recorded comprised of 25 genera of Bacillariophyta, and 23 genera of Chlorophyta. 10 genera of Cyanophyta, 4 genera of Pyrrophyta, 3 genera of Euglenophyta and 1 genus of Chrysophyta. The genera of *Diatoma*, *Surirella*, *Synedra* and *Oscillatoria* were frequently found in large number. Phylum Cyanophyta was negatively related to temperature and positively to nitrate, Phylum Chlorophyta positively to ammonia and nitrate, Phylum Bacillariophyta negatively to temperature and positively to ammonia, nitrate and chlorophyll *a*; while those phyla of Chrysophyta, Pyrrophyta and Euglenophyta had no significant relation with any parameters of water quality. The total phytoplankton were negatively related to temperature and positively to ammonia, nitrate and chlorophyll *a*. In the same year, Hourban (1997) studied relationships of water quality and phytoplankton in Bangpakong River and reported that, the phytoplankton observed, in large number, were a diatom group of *Coscinodiscus*, *Odontella*, *Navicula* and *Nitzschia* and blue green algae of *Oscillatoria*. The quantity of total phytoplankton were positively related to water temperature, pH, transparency, total suspended solid, salinity, and nitrate; while those of Division Bacillariophyta responded positively to water temperature, pH, total suspended solid, salinity, nitrate, and total phosphorus; Division Chlorophyta also responded negatively to total suspended solid, salinity, nitrate, and total phosphorus. Division Pyrrophyta responded positively to transparency, while Division Euglenophyta was positively to orthophosphate. The amount of chlorophyll *a*, ND – 84.99 mg/m^3, was positively related to water temperature, total suspended solid, ammonia and total phosphorus, as well as to the abundance of phytoplankton in Division Bacillariophyta and the total phytoplankton.

In the lotic ecosystem of the Lam Phra Phloeng Watershed, Noinamsai (2000) studied plankton biodiversity and relationships to environmental factors and reported that the morphology of the streams varied seasonally and physical and chemical factors of water had been influenced by substreams, land use and seasonal changes. A total of 109 species of phytoplankton; 9 genera, 11 species of blue-green algae, 10 genera, 28 species of green algae, 5 genera, 14 species of euglenoids, 20 genera, 52 species of diatoms and 3 genera, 4 species of dinoflangellates were identified. *Fragilaria* sp. 1 was the most common species. The phytoplankton biodiversity index (*H'*) was 0.5044. Temperature was the most important influence on phytoplankton biodiversity.

Peerapornpisal *et al.*, (2000) investigated diversity of phytoplankton and benthic algae in Mae Sa Stream, Doi Suthep-Pui National Park, Chiang Mai from April 1997 to February 1998. The 87 species of phytoplankton were found which could be classified as 5 phyla, 8 orders, 19 families and 31 genera. The majority of the phytoplankton were diatoms in the Order Pennales and the most abundant species were *Melosira varians*, *Fragilaria ulna*, *Cymbella tumida* and *Nitzschia lineris*. A total of 172 species of benthic algae were found, of which 68 species had never been recorded in Thailand before. They reprecented 3 families and 25 genera. The most abundant species were also diatoms in the Order Pennates. The majority of the species belonged to the genera *Navicula* (38 species), *Nitzschia* (23 species), *Fragilaria* (16 species) and *Gomphonema* (15 species). Furthermore, Wongrat and Ruangsomboon (2001) studied the diversity of freshwater phytoplankton in the central part of Thailand from October 1999 to September 2000 in 10 provinces, namely Bangkok, Nonthaburi, Pathum Thani, Nakhon Pathom, Sara Buri, Samutprakarn, Samut Songkram, Samut Sakorn, Ratchaburi and Phetchaburi. The total of phytoplankton comprised 124 genera, 429 species, 70 varieties and 14 forms. The major groups of phytoplankton were the class Chlorophyceae and Euglenophyceae in the division Chlorophyta. Two important orders in the class Chlorophyceae were Chlorococcales and Zygnematales consisting of 102 species and 105 species, respectively. For the Class Euglenophyceae, the order Euglenales was the most important group consisting of 103 species. From their report total of 15 genera, 128 species, 43 varieties and 8 forms have been recorded in Thailand for the first time.

Chaleoisak (2000) studied the seasonal variation of plankton in the Tha Chin River from January to December, 1996. Two hundred and six species of zooplankton were found. Numbers of species of phytoplankton in each class are as follows: Cyanophyceae (19) Chlorophyceae (63), Euglenophyceae (27), Bacillariophyceae (37), Chrysophyceae (2), and Dinophyceae (6). Numbers of zooplankton species in each phylum are as follow: Protozoa (21), Rotifera (23), and Arthropoda (6). Abundance and species composition of plankton were seasonally different; the highest number of species was recorded in summer and the lowest number was recorded in winter. Chlorophyceae and Rotifera were the most important groups in terms of number of species in the study. The highest abundance was found in summer (10,039 units/l) and the lowest abundance was in December (731 units/l). The dominant species were Cyanophyceae (*Oscillatoria* spp., and *Spirulina platensis*), and Protozoa (*Difflugia* spp., and *Arcella vulgaris*).

The ecology of diatoms in the Pasak River and relationships between diatoms and stream runoff were studied (Hempattarasuwon, 2001). The study was carried out during low water, low-high water and high water quantities. Two hundred and eighty species of diatoms were found and could be classified into 3 classes, 15 orders, 25 families and 38 genera. The majority of the diatoms were in the Order Navicula in which 119 taxa were identified. The diversity index of planktonic diatoms was lowest 0.32 in low water quantity and highest 3.54 in high water quantity. The diversity index of periphyton was lowest 1.40 in low water quantity. Planktonic diatoms had the inversed relationship with the stream runoff with the coefficient of 0.703 (a = 0.01) whereas periphyton was not significantly correlated with the stream runoff.

2.6.1.2 Lake projects

There has been a decrease in water qualities of lakes and reservoirs in Asia in recent year. This problem occurred in many parts of Thailand, and then the limnological and monitoring water quality researches began in the northern reservoirs. Peerapornpisal (1996) studied phytoplankton seasonality and limnological characteristics of the three reservoirs (Reservoir A, B and C in the Huai Hong Khrai Royal Development Study Centre, Chiangmai, Thailand and reported that most of the physico-chemical characteristics such as temperature, pH, nitrate nitrogen, ammonium nitrogen, soluble reactive phosphorus and total phosphorus did not show vertical distribution. Only oxygen saturation in Reservoir C showed a clear vertical gradient. Among the taxonomic groups, Chlorophyceae were the most species rich group, followed by Euglenophyceae, Zygnemaphyceae, Cyanophyceae, Dinophyceae and Diatomophyceae. The dominant species was the heterocystous bluegreen alga, *Cylindrospermopsis raciborskii* (Wolosz, Seenayya & Subba which is a tropical and warm temperate species. The large proportion of phytoplankton species in the three reservoirs were cosmopolitan species (60%), a small proportion was tropical species (16%) and tropical and warm temperate species (2%). The growth of phytoplankton was due to the amount of nutrients which varied seasonally. Phytoplankton biovolume showed positive correlations with some of the nutrients, the most significant correlations with ammonium nitrogen, soluble reactive phosphorus and total phosphorus. The negative correlations with water level and with Secchi depth were less pronounced. Due to the lack of seasonality in Reservoir C, correlations between physico-chemistry and phytoplankton characteristics are less clear in Reservoir. Reservoirs A and B could be categorized as eutrophic in the rainy season, mesotrophic in the cold part of the dry season, eutrophic to hypereutrophic in the warm part of the dry season whilst Reservoir C showed eutrophic status throughout the investigation.

Monitoring of water quality was carried out, using phytoplankton biodiversity as indicators. (Pongswat, 2002) The project was conducted at Ram IX lake, Pathumthani Province from February 2000 to January 2001, and reported that, phytoplankton in both lakes were classified into 6 divisions, 12 orders, 28 families, 62 genera and 95 species. Assessment of water quality indicated that the first lake was mesotrophic to eutrophic. The phytoplankton which could be used to indicate mesotrophic to eutrophic status were *Cylindrospermopsis raciborskii* (Wolosz.) Seenayy & Subsbba, *Peridiniopsis cunningtonii* Lemmermann, *Trachlomonas volvocina* Ehrenberg, *Peridinium* sp. 1 and *Ceratium furcoides* (Levander) Langhans. The second lake was oligotrophic to mesotrophic status, were *Cylindrospermopsis raciborski* (Wolosz.) Seenayya & Subba, *Trachelomonas volvocina* Ehrenberg, *Peridinium* sp. 1, *Peridiniopsis cunningtonii* Lemmernann, *Ceratium furcoides* (Levander) Langhns *and Anomoeneis vitrea* (Grunow) Ross. Furthermore, Pekthong, (2002) studied biodiversity of benthic diatoms and their application in monitoring water quality of Mae Sa Stream, Doi Suthep-Pui National Park, Chiang Mai Province reported thirty four genera compiled with 278 species of diatoms were found, 51 species of which have never been recorded in Thailand before. The species of diatoms indicating of clean water and found upstream were *Gomphonema pumilum* var. *rigidum* E. Reichardt et Lange-Bertalot, *Eunotia minor* (Kützing) Grunow and *Gomphonema clevei* Fricke. The species indicated polluted water quality were *Nitzchia palea* Kützing, *Achnanthes lanceolata* (Brebisson) Grunow, *Gomphonema parvulum* Kutzing, *Melosira varians* Agardth, *Gyrosigma scalproides* (Rabenhorst) Cleve and *Bacillaria paradoxa* Gmelin. The water quality of Mae Sa Stream could be classified as oligotrophic–mesotrophic to eutrophic depending on sampling site and seasonal changes.

In another report, Panuvanitchakorn (2003) studied the distribution of toxic blue green algae, *Microcystis* spp. and water quality in Lamtakong Reservoir, Nakorn Ratchasima Province in the Year 2000-2001. It indicated that there were nine species of toxic cyanobacteria and phytoplankton were precent in 6 divisions and 134 species. The dominant species were *Fragilaria ulna* var. *acus* (Kutzing) Lange-Bertalot, *Pseudanabaena limnetica* Komarek, *C. raciborskii and Planktolyngbya limnetica* Lemmermann. It was found that *F. ulna* showed a positive correlation with the total biovolume and tended to be positively correlated with nitrate-nitrogen. The water quality in the reservoir of Lamtakong Dam was classified to be in the mesotrophic status and in the categories 2-3, according to the trophic level and standard water quality of Thailand respectively.

2.6.1.3 Estuary projects

The human activities affected to all area of the watershed such as streams and rivers, ponds, lakes and reservoirs, especially, the area of estuaries. High nutrient concentration flowed from land to the river mouths. In the area of estuaries, there were some studies about plankton such as, Tanyaros (1993) studied the distribution of nutrient and chlorophyll *a* in Khumpuan Estuary, Ranong province during November 1991 to April 1992. The study reported that in dry season distribution of chlorophyll *a* decreased gradually toward river mouth. Chlorophyll *a* showed direct correlation with total dissolved inorganic nitrogen and silicon. In the wet season, distribution and correlation chlorophyll *a* was opposite to those in dry season. However, there was no correlation with phosphate in both seasons. Total nitrogen of bottom sediments in dry season had higher concentration than those in wet season, but total phosphorus of bottom sediment in both seasons had similar concentration.

Phromthong (1999) studied dynamics and diversity of phytoplankton in Tha Chin Estuary, Samut Sakhon Province and reported that a total of 70 genera of microplankton were collected. The highest diversity and evenness indices were observed from the phytoplankton community in rainy season. On the other hand, the lowest diversity and evenness indices were found in dry season. Maximum average density of microplankton found was 2.69×10^7 cells/l in March 1998 and the minimum value in July 1997 was 3.57×10^5 cells/l. Diatom was the dominant microplankton in the dry season 1997. Blue-green algae and green algae were more abundant in the rainy season. The dominant genera of microplankton in terms of both frequency of occurrence and the abundance consisted of the diatoms: *Skeletonema* sp., *Thalassiosira* spp. and *Nitzschia* spp. and the blue-green algae *Oscillatoria* spp. Average density of nanoplankton was 3.41×10^6 – 2.48×10^7 cells/l with the maximum density in July 1998 and the minimum value in March 1998. The most abundant nanoplankton was unidentified flagellates followed by diatoms and green algae. The abundance of phytoplankton was higher during the day time than at night. Average chlorophyll *a* concentrations of total phytoplankton were higher than other estuaries around the Gulf of Thailand with the maximum value of 38.14 mg/m^3. Most of the year, chlorophyll *a* concentrations of pico and nanoplankton was greater than microplankton except during *Skeletonema* sp. bloom. This indicated that pico and nanoplankton were the important primary producers in Tha Chin Estuary. Salinity was the major factor controlling diversity and abundance of phytoplankton in the area. The minor factors were the concentrations of ammonium and silicate. Microplankton and pico and nanoplankton relative to chlorophyll biomass were 35.14% and 64.86% of total chlorophyll *a*, respectively. The result showed the ecological rule of nano-phytoplankton in nutrient cycling and pelagic food web in Tha Chin Estuary. It also indicated the change in phytoplankton population structure due to adverse environmental conditions. However, the Tha Chin Estuary is still a high productive area in terms of primary production.

2.6.2 Socio – Economic Aspect of Watershed Management

Furthermore, there were many researches into socio-economic status and management in Thailand such as, Wattanaudomwong (1999) studied stakeholders and the water quality problem of Mae-Ping River. A holistic approach to sustainable management was taken by using a review of document, observation and in-depth interviews with representatives from eight stakeholders, 51 people. It was found that the water pollution problems of the Mae Ping River had not yet been solved due to lack of coordination among various agencies, discontinuity of project implementation and the absence of people participation. To achieve sustainability in managing water quality of the Mae Ping River it is proposed that law enhancement, the strengthening of local community and the promotion of awareness among local people should be emphasized. Involved stakeholders should try to minimize conflicts by revising their roles and compromising with each other. Guidelines for specific roles and responsibilities of each stakeholder should be clearly determined. Nubtueboon (1993) studied awareness and expected roles of the Sub-district Council Committee in participation on mangrove forest resource conservation of The Western and Eastern Areas of Pa Aou Mahachai National Forest Reservation in Samut Sakhon Province. They reported that

1) Most Sub-district Council Committee members had the medium level of awareness on Mangrove Forest Resource Conservation in Samut Sakhon Province.
2) Most of the Sub-district Council Committee members had never participated activities regarding Mangrove Forest Resource Conservation. The participated activities on Mangrove Forest Resource Conservation were at a low rate.

Watershed conservation and public participation were considered as well as watershed management. Supon (2002) studied local people's participation in the conservation of environment at Budha Udhayan Reservoir, Amnatcharoen Province and reported that the people's participation in water reservoir conservation of environment around the Budha Udhayan Reservoir was a low level. Factors affecting people's participation in water reservoir are: sex, information availability, social position and yearly family income showing a statistical significance ($p < 0.001$). Also age experience in conservation of environment program and attitude to conservation of environment showed a statistical significance ($p < 0.05$). The study recommended that water reservoir conservation of environment management should be implemented by the coordination of the people's participation, the sub-district administrative organization and other sectors concerned with budgeting, necessary equipment, water reservoir conservation, group setting, organization and society. There should be training about knowledge for water reservoir conservation. Kittayakul (1998) studied factors affecting people participation in conservation of Maesuai Watershed, Chiang Rai

Province by using questionnaires. The study reported that average income and outcome are 29,031.22 Baht and 23,118.06 Baht, respectively. Average knowledge of watershed and natural resource conservation is 33.4 %. Furthermore, the results also found that men, farmers, higher income groups, those who lived in the area longer time, more information group, group membership and higher knowledge people in natural resource conservation have more participation which accept to the hypothesis. The education background was not significant to people participation which reject to the hypothesis. Moreover, Choosri (2000) studied the small-scale fishermen participation in conservation of coastal resources: A case study of Pattani bay, Pattani Province by using questionnaires from 330 residents. The study reported that the majority of the small-scale fishermen's participation level in coastal resources conservation was low. It was found that the level of education was a statistically significant factor affecting the small-scale fisherman's participation level in coastal resources conservation. Low income and the results of the deterioration of these resources such as decreasing number of fish and marine life have forced the fishermen to spend most of their time making a living. This problem left very little time for conservation activities. The research recommended that the government and local organizations should co-operate in setting natural resources conservation projects having small-scale fishermen participate in, training in raising awareness for the conservation problems. Also, Khaisang (1992) studied the participation of local people in mangrove conservation in Trang Provice by using questionnaires. There was a low level of people's participation in both stage and type of participation in mangrove conservation. Problems and obstacles for participation were (1) lack of knowledge, (2) no time, (3) no community leader, (4) economic factors, (5) being afraid of existing illegal power, (6) lack of government officials co-operation and legal practice.

2.7 Overview of the Phetchaburi Watershed

2.7.1 General of the Phetchaburi Watershed

Phetchaburi Watershed is one of twenty-five main watersheds, which covers the area of 5,600 sq. km. It is an important watershed located in Phetchaburi Province. The main channel of the watershed, Phetchaburi River is 210 km. in length from headwater to the estuary. Kaeng Krachan Dam is located in upstream of the watershed. The watershed supplies water for electricity generation, fisheries, transportation, tourism and recreation, as well as receiving wastewater discharges as receptor from human activities (Chulalongkorn University, 1994; Land Development Department, 1999 and Royal Forest Department, 1994) In the Phetchaburi River, there are 3 major ecosystems:

a) ***Lentic ecosystem***. This system can be found mainly at the riverhead, especially at the Kaeng Krachan Reservoir which has been receiving water since 1965. The Kaeng Krachan dam is an earthen dam that connected 3 hills to make a dam of 56 meters height and 1,320 metres long, the apex of the dam is 8 metres wide while the base widest at 250 metres. Overflow passage can deliver 75 cubic metres per second. The surface area of the reservoir is 4,960 ha and it can store water up to 700 million cubic metres. The dam obstructs the original flow of the river thus creating a lentic water system. The aquatic animals can not migrate up to the river. Sediment from up river erosion caused sedimentation in the reservoir. Thus at the beginning of water storage, water quality was not suitable for aquatic animals but now it is believed that it has reached the equilibrium stage.

b) ***Lotic ecosystem***. This system can be found in the area of Amphoe Kaeng Krachan down the river, Amphoe Tha Yang just above the Phetchaburi dam and Amphoe Maung. This lotic ecosystem resulted from regulated flow of the water on the lower side of the Kaeng Krachan Reservoir for generating electricity with high flow from evening to night time. During the day time the retained water in the Phetchaburi dam will be directed to irrigational canals for agricultural uses. The flow pattern will be controlled by seasonal changes and cropping practices. Living organisms in this system will be affected by water flow.

c) ***Estuarine ecosystem***. This system is the lower end of the river to the river mouth, Amphoe Ban Laem with a length of approximately 3 kilometres. Two river mouths, the Ban Laem river mouth and Bang Taboon river mouth, mixing of fresh water from the Phetchaburi River with sea water from the Gulf of Thailand causes variation of salinity which will depend on seasonal changes and tidal ranges. Living organisms in this area are those that can tolerate the changes of salinity by using osmoregulation and ionic regulation in their body.

The office of National Economic and Social Development (1994) studied the slope of the Phetchaburi River and classified the entire river length into 3 portions:

Upper part of watershed. This part starts from Kaeng Krachan Reservoir up the Phetchaburi River to Bang Kloy River with a distance of 75 kilometres. This part has steep slope. Surface run off from Bang Kloy River and Mae Pra Don River will affect the water quality.

Central part of watershed. This part start from the lower end of the Kaeng Krachan Reservoir down the Phetchaburi River for about 67 kilometres till it reaches the Phetchaburi Dam. This area, the slope of river gradually declines. Surface run off from Huai–Pak and Mae Prachan Rivers will affect water quality in this part of the river.

Eastern coastal plain. This part starts from the lower end of the Phetchaburi Reservoir down to the river mouth with a length of 62 kilometres. The slope of this area is rather low. Water quality will get effects from community waste and agricultural land drainage.

Usages of water resources

a) For drinking and domestic uses. The demand amount of water for this purpose was 35,288,495 liters and 14,219,400 liters for cities and villages respectively
b) For agriculture. Water for agriculture came from 3,604 private wells, 686 public wells, 56 wells with water pumps, 983 ponds, private weirs and

253 irrigate canals. In dry season, people from 13,730 households used water from these sources for total area of 29,231.04 ha.

c) Tap water system. In Phetchaburi Province, 296 villages have tap water system while 250 villages do not have the system which represents 52.2 % and 45.8 % of the total villages respectively. For city in the Phetchaburi Province, there is 1 tap water office that distributes water to 1 Maung Municipality for 27,940 people. The total production of tap water was 9,532,189 cubic meter with the sale of 6,338,705 cubic meters which resulted in water losses 33.5 % (Tap Water Production Division of Phetchaburi, 1998)

Water Resources

Natural water body. The major natural body of water in Phetchaburi is the Phetchaburi River while the others consist of rivers, brooks, streams and 327 canals. Among these canals, 321 of them can be used in the dry season. There are also 29 swamps and 27 of them can be used in the dry season. Two springs can be used throughout the dry season.

Irrigation water. Water irrigations in the province consist of large and medium projects, the King's Initiated projects and small projects. At the end of fiscal year 1998, 103 projects were completed and can store water up to 766.33 million cubic meter which can feed land area of 81,364.32 ha or 60.87 % of the total agricultural land of 133,660.32 ha.

Hydroelectric station. At the end of fiscal year 1998, the Department of Energy Development and Promotion had installed 6 water electric generator stations in Phetchaburi Province which can supply water to area of 1,824 ha.

The notification of the Pollution Control Department designated of water resources in the Phetchaburi River, published in the Royal Government Gazette, General notification Vol. 166, part 72 d, dated September 9, B.E. 2542 (1999) has designated water resources in this river base on water quality and beneficial uses as follows:

From the river mouth of the Phetchaburi River at Ban Laem. Tambon Ban Laem, Ban Laem District, Phetchaburi Province, from 0 kilometer Stone up to the lower end of the Phetchaburi Dam of Ban Koh La–Om, Tambon Ta–Laeng, Tayang District , Phetchaburi Province at 61 kilometre stone was designated as standard surface water criteria Type 3 (water resources receiving waste water from some activities and from agriculture but can be used for drinking and usages by normal disinfection and general water treatment.

For those water resource from the lower end of the Phetchaburi Dam up the river to the lower end of the Kaeng Krachan Dam at 118 kilometre stone was designated as standard surface water criteria type 2 (water resources receiving waste water from some activities but can we used for drinking and usages by normal disinfection and general usages by normal disinfection and general water treatment; it can be also used for aquatic animals conservations, fisheries, swimming and water sports).

2.7.2 Land Use Patterns

The land use patterns in Phetchaburi Watershed consist of forest and mountain, water sources, agriculture, communities, industry and aquaculture (Chulalongkorn University, 1994; Land Development Department, 1988; 1999 and Royal Forest Department, 1994).

According to administrative zone, Phetchaburi Province is divided into 8 Districts, 93 Tambons and 673 Villages. There are 53 Tambons Administrative Organizations operated within the local administration.

Total population in 2002 was 459,042 inhabitants with 223,764 males and 235,278 females (National statistical office, 2002).

Land uses data in 2002 (National statistical office, 2002) showed that total area of Phetchaburi province was 622,513.76 ha. The area comprised of

a) Agricultural area is used for rice field, various agronomy activities, planting fruits such as mangoes, coconuts and others fruits as well as aquaculture. This land area is approximately covered 101,615.68 ha.
b) Forest area included productive forest, degraded forest and reforestation area. Peat swamp forests, deciduous, mix deciduous (degraded dry Dipterocarp), Eucalyptus and Arcasia plantations were also found. Total forest area was 214,474.56 ha.
c) Community area is used for residence, township, shopping centre, villages, official building and recreations with total area of 4,629.12 ha.
d) Other area was categorized as shrubs, grass land, swamps, salt farms and non specific uses with total area of 301,778.4 ha.

2.7.3 Resource Management in Phetchaburi Watershed

The management plan for Phetchaburi Watershed is the ongoing process while the impacts of land uses on the watershed have been increasing both its quality and quantity throughout of the ecosystem. As a result, many pilot projects have been developed to solve the problems in this watershed. However, most of the studies for Phetchaburi Watershed had been conducted as well as to create its management in downstream, especially municipal area. The ecological, social, economical studies on the watershed have been reported as follows:

2.7.3.1 Ecological Studies

Thamsitchai (1995) studied the growth of the service industry and the management of water resource in order to gain an overall picture of the growth direction of the service industry its demand for water and its impact on the water consumption in Phetchaburi Province. The population was composed of 45 hotels, 30 restaurants and 4 golf-courses. Secondary data were collected from government agencies concerned. Three sets of questionnaires were used for data collection. It found that the annual rainfall and streamflow in the Phetchaburi Basin had been on the decrease over the last 20 year, resulting in water shortages during the dry season. Deterioration of the water quality was found to be due to the discharge of domestic and agricultural waste water. The service industry grew from 13.09% in 1981 to 13.65% in 1991 i.e. an increase from 16 hotels and 660 rooms to 80 hotels and 3,717 rooms. Most service industries were supplied with water from the Phetchaburi Provincial Waterworks Authority, the Cha-am Municipal Water works Division, and from sanitation areas and groundwater wells. Golf - courses had reservoirs to serve their own needs. Most respondents opined that water shortage occurred during the dry season when tourism was at its peak. The hypothesis test showed that the growth of the service industry would certainly have its effects on water use in Phetchaburi Province both in the short and the long term, more or less depending on different demands for water. It is, therefore, advisable that a provincial industrial development plan, especially for the service sector, should be developed to match well with the water management plan to avoid water shortage problems in the future.

Choltimol (1995) studied trends of rainfall in Phetchaburi and Prachuap Khiri Khan Basins. The study aimed at the changes and trends of rainfall in the study areas i.e. Phetchaburi and Prachuap Kiri Khan River Basins. The observed data of monthly rainfall, annual rainfall and rainy days were used for 42 years during 1952 - 1993. The study concluded that the annual rainfall in the study areas during 1952 - 1993 fluctuated in accordance with the normal natural phenomena. However, the Phetchaburi River Basin had slightly decreasing trends about 6 mm/year. The decreasing trends of annual rainfall in the study areas were similar to those found in other regions of Thailand.

Some studies were concerned with flooding in Phetchaburi watershed such as Sawetprawitchkul (1995) studied the occurrence of floods in the Lower Phetchaburi River Basin. The study was aimed at investigating the causes of floods and flood characteristics in the Lower Phetchaburi River Basin by using (a) simulation method for various stages of water resources development plans in the basin. The studies reported that flood simulation in the Lower Basin was routed from Huai Mae Prachan. The time to peak of hydrograph is approximately 43 hours. The scenario simulations results showed that by varying reservoir storage volumes, flood hydrographs at downstream were almost unchanged in each case. However if the initial storage condition was set equal to the dead storage volume, the time to peak is delayed by 24 hours and the peak flow is reduced to about 40% of the precent condition. In addition, Pinitwattananon (2000) studied the flood susceptibility mapping in the Phetchaburi

River Basin. The study was aimed at investigating causes of floods, flood characteristics and mapping flood susceptible areas in the Phetchaburi river basin. Hydrological data of the basin were collected from reports and previous researches and reports on flood condition and damages from government agencies were also used in the study. The study reported the heavy rain from the Southwest monsoon and cyclonic disturbances are main causes of floods. Geomorphology and human induced factors such as land uses, highways, dams and embankments exerted strong influence on the type and degree of flooding.

Ongcharoensuk (2001) studied the performance assessment of irrigation project in Phetchaburi Basin. The objective of the research was to evaluate the performance of irrigation project in Phetchaburi Basin. The study was implemented using data of dry season 1998 from February to June and data of wet season 1999 from July to November. The studied reported that the performance evaluation of Phetchaburi irrigation project was well implemented. Nevertheless, all indicators in the wet season may not be used as a representative since irrigation practice was not applied for the whole season due to flood at the end of season. In addition, the project may increase irrigation area by improvement of water management at lateral and on-farm level.

Ongchotiyakul (1998) studied the analysis of rainfall and streamflow gaging networks in 25 major basins of Thailand by collecting data of the number of rainfall and streamflow gaging stations from various agencies. The adequacy of the station networks were then analyzed by comparing with those required by the WMO (World Meteorological Organization) criteria. The study reported that the numbers of existing rainfall stations were greater than where as the streamflow stations were close to those required by the WMO criteria. However, the existing rainfall stations and streamflow stations are mostly located in the lower part of the major basins. In order to meet the WMO network criteria especially in the upper subbasins, additional 295 rainfall stations and 201 streamflow stations were recommended with the total were 145.15 million baht (1999 fiscal year). Considering the Phetchaburi Watershed, there are many existing rainfall stations but these stations including streamflow stations were mostly located in the downstream of the Watershed. The hydrological data was not complete for calculating in the whole watershed. Thus it might be affected to many researches in the watershed.

In recent year, the remote sensing and GIS have been developed to use for studying the land use patterns such as one study in this area.(Tongthap, 1998) This study investigated sustainable watershed development by using remote sensing and GIS: a case study at Huai Sai Royal Development Study Centre, Phetchaburi, Thailand. The research was an attempt to develop and evaluate a methodology for assessing the land use analysis the land use changed, land misused, and watershed classification by integrating remote sensing and GIS technology. The result showed that during the period of ten years, dramatic land uses change took place resulting from population increase, mismanagement and land misused. Agricultural area expanded to the high elevation area and steep slope at the expense of losing forest area. The most important change in the study area was conversion of upland crops into bars soil and grassland. The result also showed that major area of farm was used for upland crops, paddy field, and mixed orchard in unsuitable area at Huai Sai Watershed, sustainable agriculture and natural resources management were needed. Watershed class's map was proposed to develop land utilization. It could be anticipated that, the watershed classification regulation would contribute to long term benefits to water resources development and sustainable watershed development project if it could be efficiently implemented throughout the area.

There have also been some studies about the impacts of land use in the watershed areas such as, Nilthanom (1995) studied the impact of land use evolution on stream flow and some water qualities of Phetchaburi Basin. The study were based on various sources of historical data including forest area made available by the Royal Forest Department, water quantity and suspended sediment recorded by Royal Irrigation Department, the precipitation data collected by the Royal Irrigation Department and Meteorological Department. The aforementioned data during 1973 - 1991 were analyzed using the multiple regression analysis. The results of the study indicated that land use changes was a major factor which caused the reduction of forest area in the Lower Phetchaburi, Huai Mae Prachan, Upper Phetchaburi and Phetchaburi Watersheds from 24.38, 85.87, 81.52, and 68.49 percent in year 1973 to 8.60, 38.67, 62.82, and 45.39 percent in year 1991, respectively. Most of the areas were converted to cultivated land. It was also found that after changing the land use pattern, the runoff potential within Huai Mae Prachan and Phetchaburi Watersheds was increased.

However, within the Upper Phetchaburi Watershed, the runoff potential depended on the quantity of the water regulated from the reservoir. Deforestation showed insignificant impact on water quantity and suspended sediment in all watersheds. However, it was found that urban and agricultural areas of Phetchaburi Watershed, which induced the aquaculture activities, were the major factors that caused the degradation of water quality to be unsuitable for fishery conservation. The water quality is classified as type 3 and 4 of water quality standard for surface water and sea water area. It was recommended that the national policy should pay more attention to seek for the suitable measures to reduce the rate of deforestation. In addition, it was also important to introduce the integrated land use and human activities according to water use to reduce the drought problem within Huai Mae Prachan Watershed, and water treatment control from the community area and other activities in urban area.

Powtongchin (1995) studied the impact of tourism on land use in Phetchaburi province with the two objectives those were 1) to study the role, the relationship and the impact of tourism on land use in Phetchaburi and 2) to propose guidelines and measures to alleviate negative impacts within the study area. It was found that tourism in Phetchaburi has given rise to land use expansion in two ways. First, an accommodation in the form of hotel and resort has been expanded to cater for tourists. Second, real estate those make use of tourism as campaign spot such as condominium housing and golf course have also grown rapidly. Such expansions have been concentrated around four tourist areas: the shoreline area, the urban area, the Kaeng Krachan Reservoir area and the western area of Cha-am District. The impact can be classified into 4 categories: physical impact, i.e. land form and water resources; ecological impact, i.e. forest and mangroves; the impact on human use values, i.e. land use and infrastructure development; and the impact on quality of life values, i.e. economic and social conditions, aesthetics, and recreation. The most impacted area was the shoreline. The next most impacted was the western area of Cha-am District. For the Kaeng Krachan area, the impact level was fair. No highest levels of the impact have occurred in the urban area. To alleviate and minimize the negative impact, the following measures were proposed: 1) zoning the area into development area, controlled area and conservation area; 2) implementing taxation measures to control land development; 3) using taxation measures to control land speculations and supporting agricultural occupations.

Furthermore, there were some studies in the impacts of land use in the coastal area of Phetchaburi Watershed. Bunyachatphisuthb (1999) studied the relationship between land use and coastline change in Phetchaburi and Prachuap Khiri Khan Provinces by using remote sensing technique. The study showed that coastline change at any shoreline segment has significant relation with land use/land cover at that segment at significant value less than 0.2063. The high density built-up area always has high probability of erosion, while bare always has low probability of erosion. In analysis of relationship between coastline change at any shoreline segment with land use/land cover at that segment as well as the adjacent up drift segment, it was found that the relation between land use/land cover with coastline changes could not be concluded. The logistic model did not exhibit any statistical relationship between individual of land use/land cover with the coastline change at significant value greater than 0.1581. When the model contained more land use/land cover variables by adding up drift land use/land cover information, the significance increased ($p<0.005$). In addition, Boutson (2000) studied tidal currents, sedimentation and some physical properties of surface water at coastal area of the Laem Pak Bia, Ban Laem District, Phetchaburi Province. With regarding to Lagrangian and Eulerian theories, they were used for the study of tidal currents circulation along the Laem Pak Bia Coast, Phetchaburi Province, focusing on the speed, direction and pattern of current circulation during flood and ebb of spring tide in 1999. The study revealed that current circulation was mainly influenced by tides and coastal topography. Surface salinity at the Phetchaburi river mouth (Klong Ban Laem and Klong Bang Taboon) and the Laem Pak Bia were 10 - 28 and 26 - 32 ppt respectively. Salinity increased when saltwater is was moving landward. The average suspended solid sedimentation rate at the Laem Pak Bia and the Phetchaburi river mouth were 1.9 and 2.2 g. dry weight/sq.m./day respectively. The coastal topography, seasonal change, and fresh water outflow from the river, especially from the Phetchaburi and the Mae Klong River, influence the salinity, sea surface temperature, water depth, and suspended solid sedimentation rate.

Beside those above impacts, Chaisamran (2000) studied the environmental impact of wastewater from communities associated with a lagoon system and natural mangrove forest from Laem Phak Bia Project, Ban Laem District, Phetchaburi Province. The research used the water quality and attitudes of local people toward the principle of conservation, revival of water resources and development of mangrove forest resources as indicators. The attitudes of 102 people were studied by conducting interviews. The study found that the wastewater from communities associated with a Lagoon System did not directly impact the water quality in the mangrove forest yet. The suggestions from the results of this study are that there should be a campaign of implantation of ideas and realization in communities so that people can understand and be conservation-minded. Promotion should be carried out by holding training, disseminating information, making public relations, giving knowledge and creating attitudes and activities on conservation, revival and development of natural resources to people.

According to those land uses in Phetchaburi Watershed, the water qualities in the area decreased from the past. There were many researches in water quality such as; Yingyong (1996) studied BOD and COD removal in Phetchaburi Municipal waste water treatment with alternated flooding and drying of soil and plant system, and reported that flooding times had significant effects on BOD removal but no significant effects on COD removal. The suitable flooding time for BOD and COD removal was 5 days and *Cyperus corymbosus* was the suitable plant to be used. In addition, Mahasinpaisal (1996) studied comparison of some water quality between forest and agricultural areas at Huai Maraew, Kaeng Krachan National Park, Phetchaburi Province. He reported that the water quality in forest areas and agricultural areas at Huai Maraew was not significantly different in most parameters and it was under standard of natural water excepted in some month. However, the hardness and total solid had a trended to be deterioration. Eventually, water quality was under natural standard water quality but forest protection and chemical use in agricultural area must be controlled because Huai Maraew is on of the upstream of Kaeng Kranchan Reservoir.

Furthermore, Utokasenee (1998) studied the potential of Phetchaburi River for absorption of overview from a municipal wastewater collecting system, Phetchaburi Province and reported that dissolved oxygen in Phetchaburi River varied in range of 4.9 – 6.7 mg/l and BOD_5 varied between 1.3 – 1.8 mg/l which met surface water quality standard of class 3. For sea water quality, all stations met seawater quality standard except the station at Bang Ta Boon gulf and Ban Laem gulf in rainy season were below standard. The results of the domestic wastewater of Phetchaburi municipality had an average BOD_5 of 557.9 mg/l and COD Ration were 2 : 1. Results concluded that Phetchaburi River could absorb municipal wastewater overflow from collecting system. However, wastewater discharge flow should be under condition of oxygen balance, stream flow and maximum BOD_5 loading at this time.

Prongsa (2000) investigated the concentrations of some heavy metals in edible sea animals consisting of bloody clam, blue swimming crab, mullet and silver whiting fish at the coast of Laem Phak Bia Waste Water Treatment Project, Phetchaburi Province. The comparison between the sites at the Project area and the Ban Laem (reference site) indicated that there was no significant difference, except zinc in the significantly high level in bloody clam from the coast of the Project during the rainy season and the southwest monsoon. However, the concentrations of 4 heavy metals in sea animals investigated in this study are well within the acceptable levels for consumption.

Information system is also used for water quality monitoring as well as resource management of the Phetchaburi River. (Meankeaw, 2001) The output as information system will be taken to support the decision-making, plan and policy definition about water quality in the Phetchaburi River. The most tools used in system development are called SDLC (System Development Life Cycle). The result of the study was that the database was completely designed, along with information system or program application as well as the program installation guide and user manual. In addition, the Pollution Control Department (2002) studied the development project on biological indicators of pollution in the Phetchaburi River and the study reported as follows; 11 groups of biota were collected and 163 species were identified. The species collected consisting of 41 species of fishes, 33 species of phytoplankton, 8 species of zooplankton, 32 species of aquatic plants, 18 species of arthropods, 17 species of mollusks, 6 species of parasites, 5 species of protozoa and 1 species each for echinoderm, reptile and amphibian. These species are those commonly found in fresh water habitats in Thailand. Based on the water quality index, water quality in the Phetchaburi River was also designated into 3 classes. Clean water quality is indicated by WQI = 71 – 100; 51 - 71 as moderate quality and less than 50 as low quality. The living collected biota could be used as biological indicators for water quality of Phetchaburi River by using their corresponding species indicator value.

As for the study of freshwater ecology, there were a few studies in this area. Department of Fisheries (1988) reported that phytoplankton diversity and an average of phytoplankton density in Kaeng Krachan Dam were 22 species and 5.61×10^5 cell/m^3, respectively. In addition, there was a marine phytoplankton research at the coastal area. Ringluen (1999) studied the diversity of phytoplankton in different habitats at the Laem Phak Bia, Ban Laem District, Phetchaburi Province between June 1998 and May 1999. The water samples were collected from 4 different habitats: mangrove forest at Laem Phak Bia, coastal sea at Laem Phak Bia, E-Add canal and mangrove forest at Ban Panern. There were 5 Phylums, 27 Families, 56 Genera of Phytoplankton: The most abundantly found were the Bacillariophyta and the Cyanophyta. Diversity Index of Phytoplankton was highest in 0.121 at the mangrove forest at Laem Phak Bia, compared to 0.08, 0.06, and 0.043 of the coastal sea, mangrove at Ban Panern and the canal, respectively. The study also found nutrient in mangrove forest at Laem Phak Bia were higher than in other areas. Therefore, diversity of phytoplankton at Laem Phak Bia was also higher than in other habitats

2.7.3.2 Socio-economic Studies

The urban development and planning in the future should throughly understand and realize how the community had developed from the history. Urbanization in many levels related each others and changed from time to time must be regarded. Besides, it has been believed that problem solving and urban planning in the future must be contributed by people. Visessumon, (1998) reported that Phetchaburi Province was a center of transportation and tradition of the Western part of Thailand. Urbanization developed rapidly after Pechkasem Road was routed through Phetchaburi Province, anyway, some communities were developed by themselves. By the reasons, eventhough there was not any urban development process, some communities were developed by local people.

Based on the socio-economic point of view, there were some researches in this area such as; the studied of socio-economic change in Phetchaburi between1857 to1917, from the Ayutthaya to the early Ratanakosin period. It was found that the central government of the Thai Kingdom recognized the importance of Phetchaburi in several aspects. This became the basis for socio-economic change in the city of Phetchaburi in the period under study. The important factors behind these changes can be divided into outside factors and inner factors. The outside factors consisted of the interest shown by Royalty and high nobility such as King Mongkut, King Chulalongkorn and the "Bunnag" family together with the American missionaries. The inner factors included the growth of Phetchaburi as a result of the improvement in communications and the growth of the economy together with the increase of the labor force within the area. These factors led to significant change in the physical, the position of resort, social structure and intellectual life of Muang Phechaburi. The establishment of King Vajirawut's new palace at "Bangta-lu" beach in Phetchaburi in 1917 and the southern railway from Bangkok to Hua-Hin brought people to the seaside more and more. As a result, Phetchaburi's importance declined (Asawinanont, 1991).

Land Development Department (1999) studied the socio-economic status of the farmers in the upper part of Mae Nam Phetchaburi sub-basin, crop year 1997 – 1998 and reported that this area had important problems. People increased from the past, the land uses were unsuitable in this area and there was low water supply in the dry season. In addition, most agriculturists had low level of education (89.75% of all agriculturists). The economic status is not good because the agricultural products were not worthwhile to invest in. Then the report suggested that 1) this areas must improve natural water resources and system irrigation 2) the communicate information about agricultural techniques must be increased for people in the area by government authorities (Land Development Department, 1999).

In addition, the public participation and conservation studies were applied to improve the development of Phetchaburi Province. However, most researches were applied in downstream areas of Phetchaburi Watershed, such as, domestic wastewater and mangrove forest managements and sustainable tourism. Yimyam (1997) studied local people's behavior in conserving Phetchaburi River: A case study at Tayang Sanitary District, Tayang District, Phetchaburi Province. The purpose of the study was to study the local people's behavior in conserving Phetchaburi River by using the structured interview. The finding of the study were

1) The people's behavior in conserving Phetchaburi River is moderate level according to three point scale devised by the researcher.
2) Factors affecting people's behavior in conserving Phetchaburi River in Tayang Sanitary District area.
   2.1 Age of the population and duration of residency are statistically significant at the 0.05 level.
   2.2 Marital status, period of living and income (per month), are statistically significant at the 0.01 level.
   2.3 Level of education and occupation are statistically significant at the 0.001 level.
3) The motivating factor affecting people's behavior in conserving Phetchaburi River of people in Tayang District is their information concerning Phetchaburi River. Phetchaburi River obtained is statistically significant to people's behavior in conserving Phetchaburi River at the 0.001 level.

Most of this people have problems regarding waste water treatment in the river and the use of river water is insisted by presence of waste water. They also have the lack of information on river or canal conservation. In addition, Songkorn (2000) studied knowledge and consciousness regarding domestic wastewater of people in Phetchaburi Municipality, Phetchaburi province by interviewing 420 people in Phetchaburi Municipality, Phetchaburi Province. The study reported that most people had knowledge and consciousness regarding domestic wastewater in middle level and high level, respectively. The differences of knowledge regarding domestic wastewater were statistically significant level at 0.05 based on age, occupation, education, income levels and sources of information received. On the other hand, there was no variable affecting on consciousness regarding domestic wastewater at statistically significant level 0.05.

Besides, Sillapasatham (1995) studied the development of value about forest conservation of mathayomsuksa 3 students of the Suksasongkroh Phetchaburi School by using extra curricula lessons entitled forest conservation. The purposes of the study were 1) to design an extra curricula lesson entitled forest conservation for mathayomsuksa 3 students of the Suksasongkrohphetchaburi school 2) to design the values-test and 3) to develop value about forest conservation of the students. The 30 students were obtained by simple random sampling method and use 4) instrument those were; a) the extra curricula lessons entitled Forest Conservation, b) the value-test, c) the behavior observation checklist, and d) the questionnaires about the opinions of the activities. The results of the study showed that: 1) there was a significant development of the values about forest conservation of the students at the level of .05, 2) the student showed behavior which leads to the development of values, 3) the students agreed that the activities in the lessons could help them improved in various aspects which is beneficial to the development of the values about forest conservation. Marasee (2000) studied people participation in the conservation of the mangrove forest: A case study of Moo 10 Ban Samukke Tumbon Bankunsai, Ban Laem District, Phetchaburi Province. The objective of the research was to study participation and factors influencing participation of the people in the conservation of the mangrove forest by using in-depth interviews and a participatory approach. The study showed high participation in the conservation of the mangrove forest. But villagers' participation was mostly informal. The problems and obstacles in their participation were identified by respondents. There was no support and no adequate information on the conservation of mangrove forest from the government officers.

Besides, Jirojkul (2001) studied an application of the Contingent Valuation Method in valuing a mangrove forest of Tambol Leam Pak Bia, Amphoe Ban Leam, Phetchaburi Province by employing questionnaires to interview 238 random sampling. The result indicated that the value of willingness to pay for mangrove forest protection was 709,738.97 baht per year. The average value of willingness to pay and willingness to accept compensation was 52,849,113.98 baht per year. However the projects must be continued in the process of construction and considered to reduce the socio-economic and environmental problems in the municipality. Most projects were continued emphasizing the water pollution reduction in municipal areas.

According Phetchaburi Province is a famous tourist attraction. Many hotels and restaurants, resorts have been expanded to cater for tourists. the most impacted area was the shoreline, especially the western area of Cha-am District (Powtongchin, 1995). Thus, some studies tried to improve these impacts. Srisatit (1999) studied the participatory role of the local inhabitants for the sustainable development of Cha-am beach, a famous tourist attraction of Phetchaburi Province. The study was focused on the past conditions of the beach compared with its present conditions, which have changed tremendously since the influx of larger numbers of tourists. The study showed that the problems of the beach include encroachment of the beach by hotels and restaurants, of some areas of Ruamjit Street by street vendors, unreasonable high food prices, heavy traffic on weekends, insufficient parking area and shortage of running water as well as certain environmental problems. These problems affected both the people and the local culture. The researcher proposed various approaches to improve the beach including the following: raising public awareness, encouraging consciousness of the environment, teaching appropriate use and preservation of natural ocean resources and promotion of local participation in determining necessary rules and regulations for the achievement of the above objective: The ultimate goal of the proposed strategies was to ensure that the self-supporting local society, under changing economic conditions, can survive while promoting sustainable tourism development in the region as well as preserving the unique culture and traditions of the Cha-am people.