CHAPTER IV

RESULTS AND DISCUSSION

4.1 The Climate

Based on the secondary data of Phetchaburi province, the climate of the area is classified as a tropical zone. The air temperature of the study period is shown in Figure 4.1. The temperature ranged from 25.6 to 29.5 $^{\circ}C$. The coldest month was January (2001) and the hottest was April and July (2002). The air temperatures in the year 2002 were slightly higher than average monthly temperatures (1981 - 2001) that is shown average annual monthly temperature as 28 $^{\circ}C$ in Figure 4.2.

According to the relative humidity, the highest value was 80% in March (2002) and the lowest was 72% in December (2001) (Figure 4.3). The relative humidity slightly varied throughout the year 2002. In addition, the values were similar to the average relative humidity (1977 - 2001) that is shown average annual relative humidity as 77% in Figure 4.4.

There are two seasons, the wet and the dry seasons in the area. The wet season occurred from May to November (2002) (Figure 4.5). The highest rainfall occurred in March (2002) at 168.4 mm and the lowest in February (2002) at 0.00 mm. Pollution Control Department (2003) reported that there was high rate of rainfall including a long period of rainy season in the year 2002. Then, the rainfalls in year 2002 were higher than the average monthly rainfalls (1981 - 2001) as shown in Figure 4.6 in which the average annual rainfall was 989.6 mm.

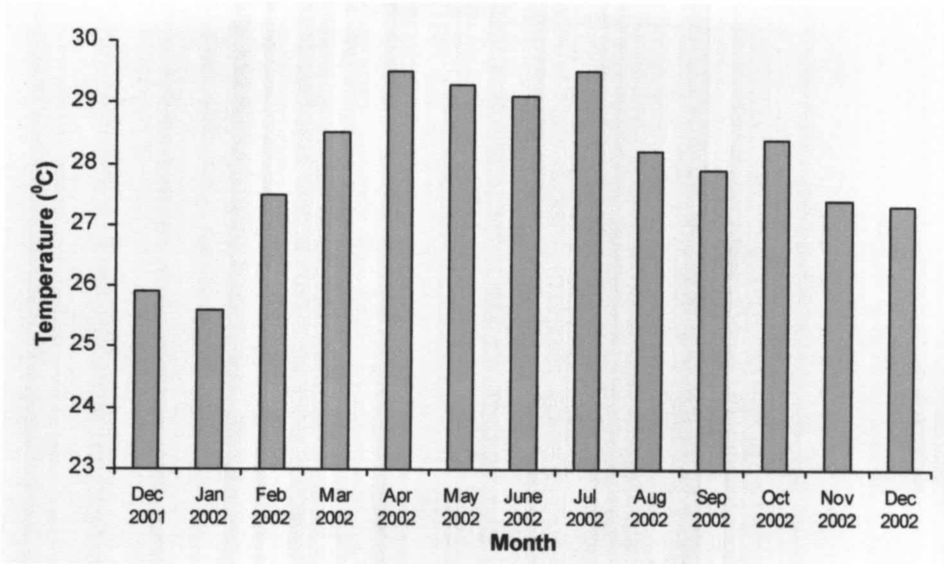


Figure 4.1 Monthly temperature of Phetchaburi Province in December 2001 to December 2002

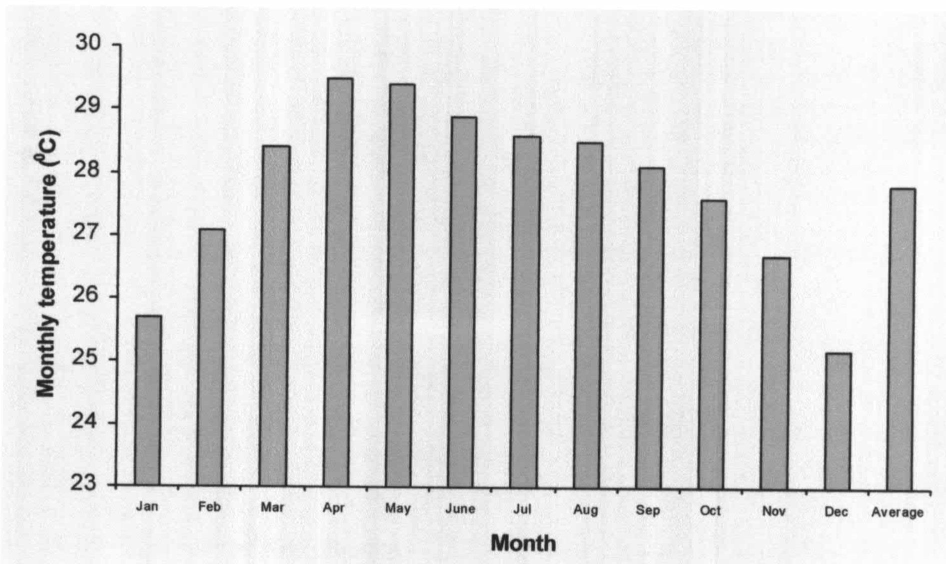


Figure 4.2 Average monthly temperature of Phetchaburi Province from 1981 to 2001

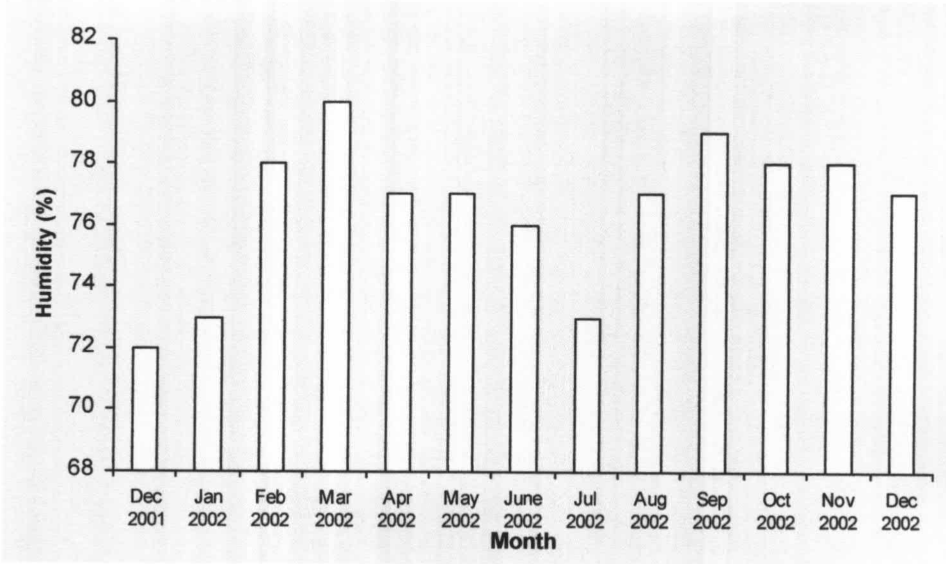


Figure 4.3 Monthly relative humidity of Phetchaburi Province in December 2001 to December 2002

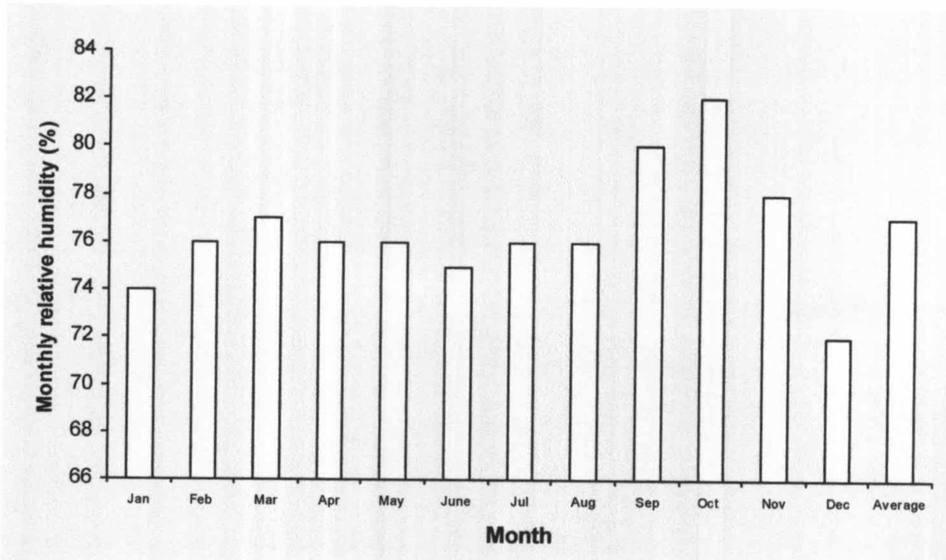


Figure 4.4 Average monthly relative humidity of Phetchaburi Province from 1977 to 2001

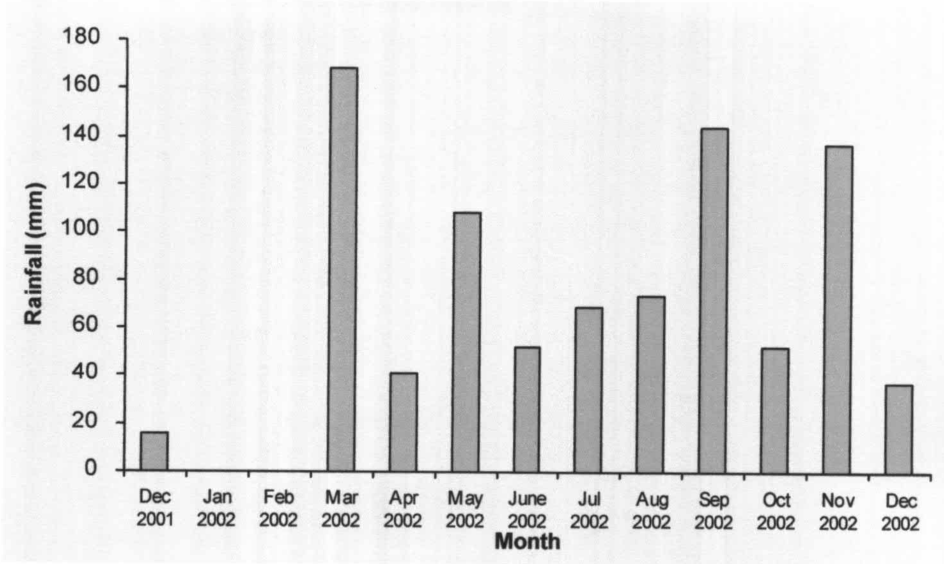


Figure 4.5 Monthly rainfall of Phetchaburi Province in December 2001 to December 2002

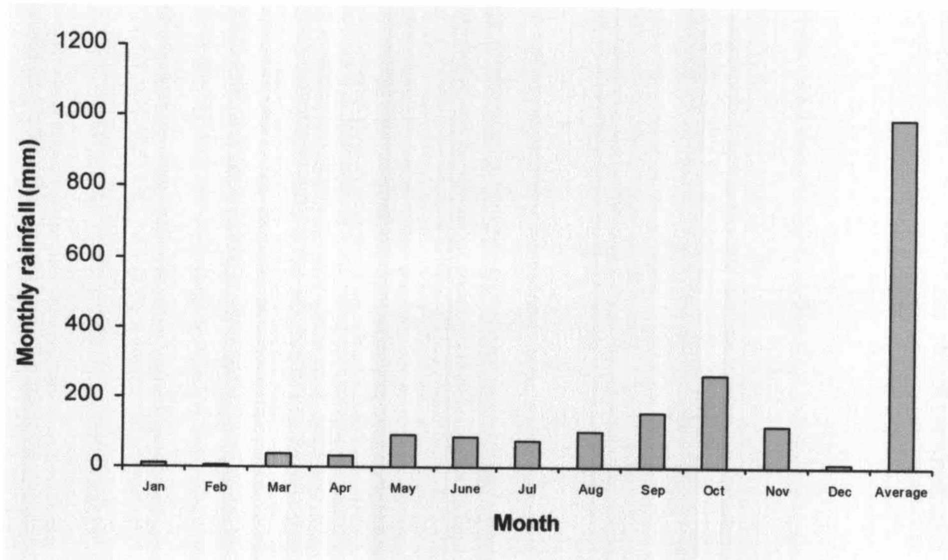


Figure 4.6 Monthly rainfall of Phetchaburi Province from 1981 to 2001

4.2 Land Use Patterns

Phetchaburi Watershed covered the area of 5,092 sq.km. It covered most of the area of Phetchaburi Province (4,561.12 sq.km.), some parts of Ratchaburi Province (517.43 sq.km.) and some parts of Samut Songkram Province (13.00 sq.km.). Upon overlaying a land use map, it showed great forest and agricultural areas at 3,480.75 sq.km. (68.36%) and 1,286.38 sq.km. (25.27%), respectively (Table 4.1). The rest consisted of miscellaneous areas (2.66%), urban and built-up areas (1.92%), waterbody (1.16%) and aquacultural areas (0.64%).

This study divided the watershed areas based on the ecosystem types. Phetchaburi Watershed was divided into three subsystems. Land use patterns of all three subsystems were presented in Table 4.1 and their percentage in Figure 4.7.

Subsystem I was located at the upstream of the watershed and covered the area of 1,798.10 sq.km. All of the areas in this subsystem was in Kaeng Krachan National Park. Then the 99.52 percent (1,789.51 sq.km.) was forest areas. The rest were waterbody and agricultural areas at 0.26 and 0.22 percent, respectively. The agricultural areas of the subsystem I were along the Phetchaburi and Mae Pradon rivers. About 300 families live in this subsystem and most of them are agricultural (National Statistical Office, 2002).

Subsystem II was Kaeng Krachan Reservoir and surrounding areas. It covered the area of 318.34 sq.km. This subsystem consisted of forest areas (70.01%), waterbody (42.30%), miscellaneous areas (9.59%), agricultural area (7.58%) and urban and built-up areas (0.53%). Kaeng Krachan Reservoir is the biggest waterbody of the watershed that was located in subsystem II. The reservoir supplies water for electricity generation, agriculture, fisheries, transportation, tourism and recreation.

Subsystem III was located at downstream of the watershed and covered the area of 1,468.37 sq.km. This subsystem was had the biggest area of the watershed including municipal area of Phetchaburi Province. Most of the area was flat plain, so it was very suitable for human settlement and agriculture. The land uses in this subsystem consisted of forest areas (49.36%), agricultural areas (42.30%), miscellaneous areas (3.53%), urban and built-up areas (3.22%), aquacultural areas (1.09%) and the smallest areas of waterbody (0.51%).

The Pollution Control Department (2002) studied the land uses along the Phetchaburi River and Kaeng Krachan Reservoir within 2 kilometers perimeters. They reported that there were five types of land use in the area of 453 sq.km. These land uses consisted of agricultural areas (263.44 sq.km.), forest areas (123.05 sq.km.), built-up areas (25.50 sq.km.), water resource areas (0.87 sq.km.) and other area (8.86%). This report indicated that the agricultural area was the biggest area of land use type at 58.15 percent. That meant high fertilizer and pestiside uses along the river banks and surrounding the reservoir. Then they could contaminate the waterbody, especially in the rainy season.

However, the land use patterns that were presented in each subwatershed were different. The effects of them were also different. Based on the population of Phetchaburi Province, National Statistical Office (2002) reported that the population in year 2001 was higher than 2000. This might be the same trend each year. The fact is the more the population, the more the water demands and the more waste water in the watershed.

Table 4.1 Land use classification of Phetchaburi Watershed

Land use classify	Area (sq.km.)			
	Subsystem I	Subsystem II	Subsystem III	Total
Forest areas	1789.51	222.88	1468.37	3480.75
Waterbody	4.69	39.11	15.12	58.92
Miscellaneous areas	-	30.54	105	135.54
Agricultural areas	3.89	24.13	1258.36	1286.38
Urban and built-up areas	-	1.68	95.91	97.59
Aquacultural areas	-	-	32.36	32.36

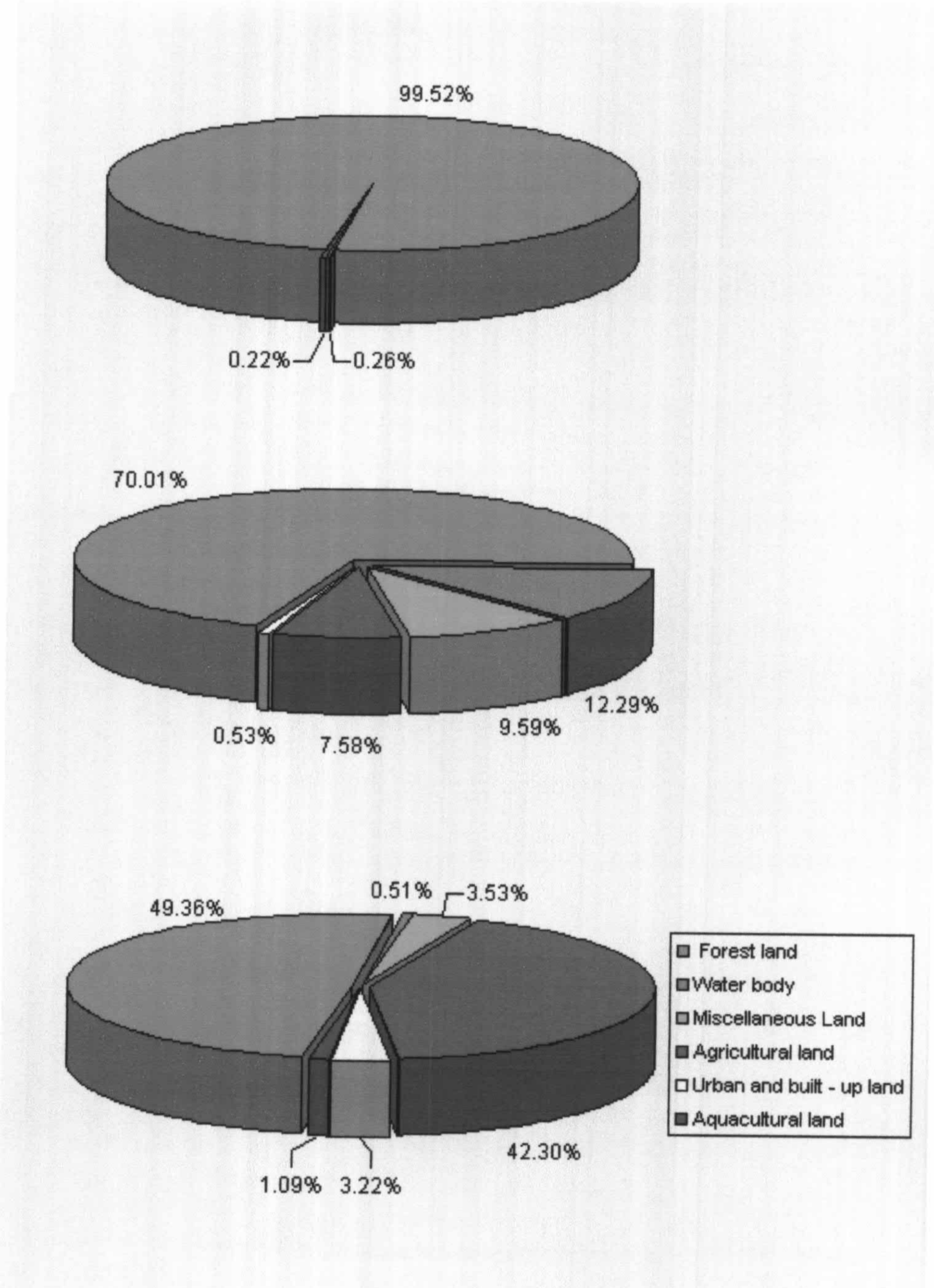


Figure 4.7 Percentage of land use patterns in the subsystem I (A), the subsystem II (B) and the subsystem III (C)

According to Figure 4.8, the water demands indicated that the highest demand in the watershed was the agriculture demand at 766.82 x 10^6 m^3 (97%). The urban and the industrial demands were at 14.06 x 106 and 8.54 x 106 m^3, respectively.

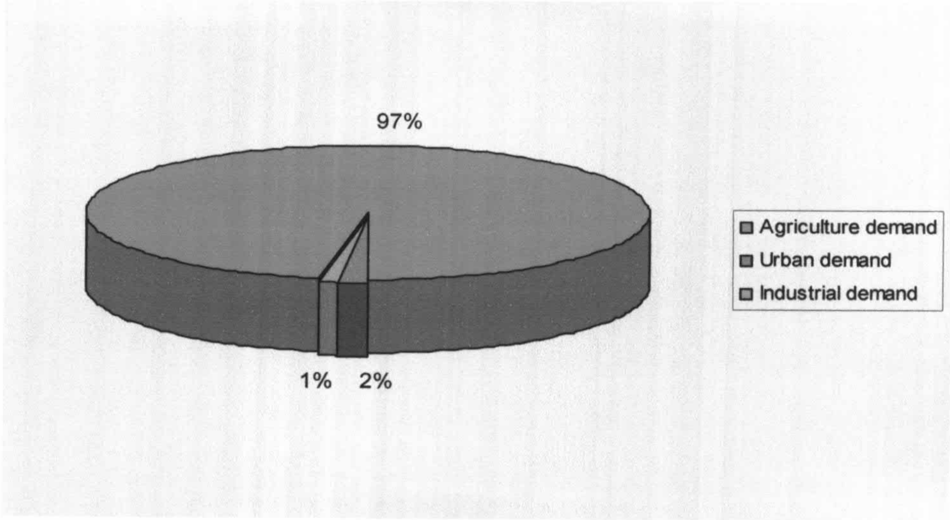


Figure 4.8 Percentage of the water demands in Phetchaburi Watershed based on Phetchaburi Province

Source; Pollution Control Department, 1997

Considering the water pollution, there are several types of pollution sources which cause the declining of water quality in rivers and streams on the watershed. Then the discharges from different land uses varied in BOD loading. The comparison of BOD loading discharged from 4 different pollution sources were shown in Figure 4.9. Based on the municipality and sanitary district, the highest BOD loading came from urban areas.

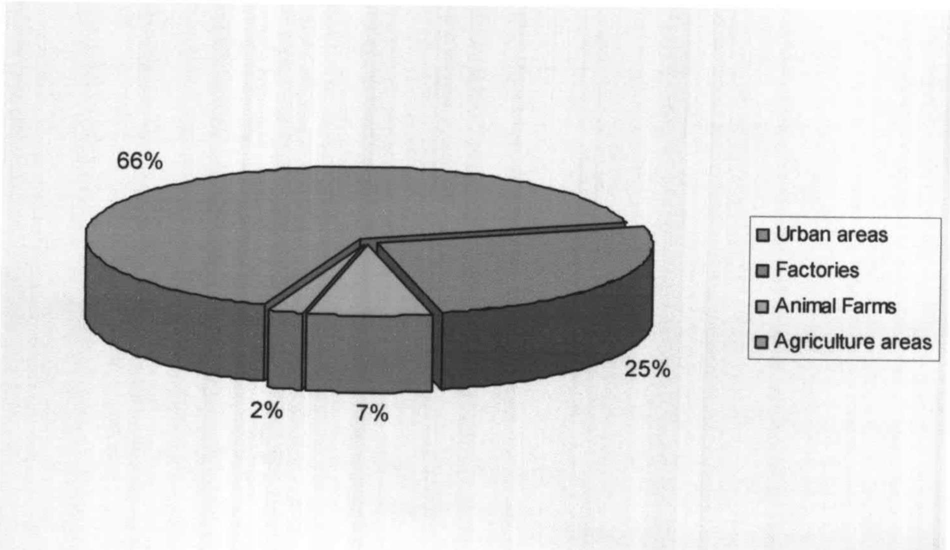


Figure 4.9 BOD loading by municipality and sanitary district based on Phetchaburi Watershed

Source; Applied data from Pollution Control Department, 1997

4.3 Ecological Relationships of Subsystem I

As results, the ecological parameters as physico-chemical parameters were shown in relation to seasonal variation and locality in subsystem I (upstream of Phetchaburi Watershed)). In this subsystem, all areas were in the Kaeng Krachan National Park and almost all of the areas are natural forests. However, at station P1 (head water of Phetchaburi River) there are about 122 families of Karang people who live under the collected station, and at station P2 (Mae Pradon Subwatershed) there are 12 families. In addition, there are about 100 families of Thai people who live along the river in this subsystem. All of them are agriculturists and they are situated along the river banks up to the area above Kaeng Krachan reservoir.

4.3.1 Physical Parameters

The physical parameters were measured along the station P1 to P3 from upstream right up to approaching the inlet of Kaeng Krachan reservoir. They contained as the following:

4.3.1.1 Depth

The maximum depths of the three stations in subsystem I varied from 0.80 ± 0.00 to 15.0 ± 0.71 metres. The highest of the maximum depth was 15.0 ± 0.71 metres at station P3 at the beginning of the wet season (June 2002) and the lowest of maximum depth was 0.80 ± 0.00 metres at station P1 at the end of the dry season (April 2002) (Figure 4.10). The maximum depth was high in the wet season (June 2002) because of high rainfall and high surface water inflow from the upstream. The maximum depth remained high at all stations in subsystem I until the end of the wet season.

Station P1 was at the head water of Phetchaburi River. At this station the water level was different from season to season. The depth increased rapidly in the wet season because of flooding from high land. At station P2 it was a small subwatershed that had water supply all year round, so the maximum depth was not different throughout the year. However, station P3 was located at the area of the main river of the watershed above the Kaeng Krachan reservoir. Then the maximum depth of water was high throughout the year and higher than station P1 (head water) and station P2 (Mae Pradon Subwatershed). In addition, the Pollution Control Department (2003) reported that there was a high rainfall in all regions of Thailand in the year 2002 and this might be the reason for better surface water quality in natural water resources.

The water depths of subsystem I were related to the seasons, especially at station P1 and station P3 (upstream of Phetchaburi River). The average depths in the wet season were higher than in the dry season, except at the beginning of the dry season (December 2001) because of the high volume of water in the wet season of 2001.

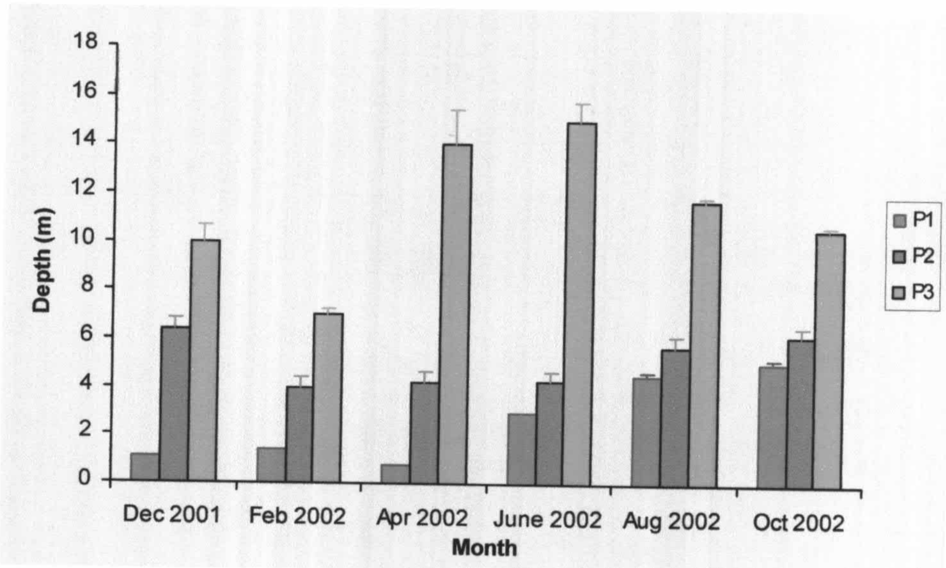


Figure 4.10 The maximum depths in subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

4.3.1.2 Transparency Depth

The averages of transparency depth in three stations varied from 0.32 ± 0.03 to 1.80 ± 0.07 metres due to seasonal variation. The highest average of transparency depth was 1.80 ± 0.07 metres at station P3 in the middle of the dry season (February 2002) and the lowest average of transparency depth was 0.32 ± 0.03 metres at station P1 in the middle of the wet season (August 2002) (Figure 4.11). The high surface water inflow increased turbidity of the water and reduced transparency depth in the wet season (June 2002) which correlated with suspended solid. In addition, station P1 was located at a high sloping area at head water so the surface water from the forest had lots of turbidity because of soil erosion and high flow of surface water throughout the wet season. Station P2 and P3 were an agricultural areas along the river banks, so there were high soil erosion and high enrichment with fertilizer and nutrients. In addition, this study found that station 2 had high chlorophyll *a* concentration, especially in April 2002 chlorophyll *a* concentration was at its highest (Figure 4.23). It also found that the phytoplankton density was high in this period (Figure 4.22), so these reasons in turn cause the decrease in the value of transparency depth in station P2. The transparency depths in all three stations in subsystem I were significantly different within the seasons at the $p = 0.05$ (Table 1, 2 and 3 in Appendix E).

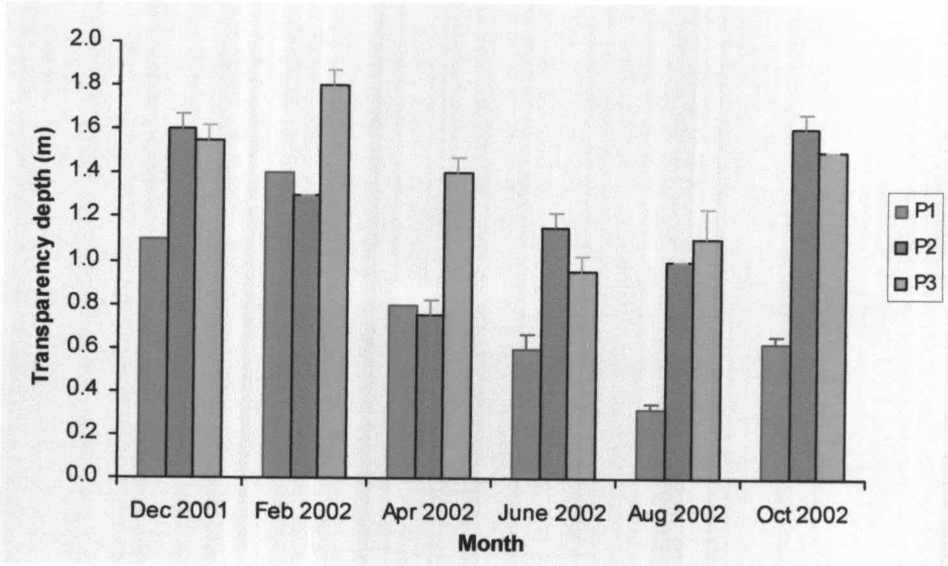


Figure 4.11 Average of transparency depth in subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

4.3.1.3 Water Temperature

The changes of the water temperature were correlated to the seasons. The averages of water temperature ranged from 23.40 ± 0.00 °C to 32.00 ± 0.00 °C. The highest average of water temperature was 32.00 ± 0.00 °C at station P2, at the end of the dry season (April 2002) and the lowest average of water temperature was 23.40 ± 0.00 °C at station P1 in the wet season (June and August 2002) (Figure 4.12). Station P1 was located at high altitude and surrounded by forest, so the water temperature was lower than station P2 and station P3 throughout the year. The water temperatures of all stations decreased in the wet season. However, the highest water temperature was in April at all three stations. The averages of water temperature at all stations in subsystem I were significantly different within the seasons at the $p = 0.05$ (Table 1, 2 and 3 in Appendix E) and related to air temperature (Figure 4.1).

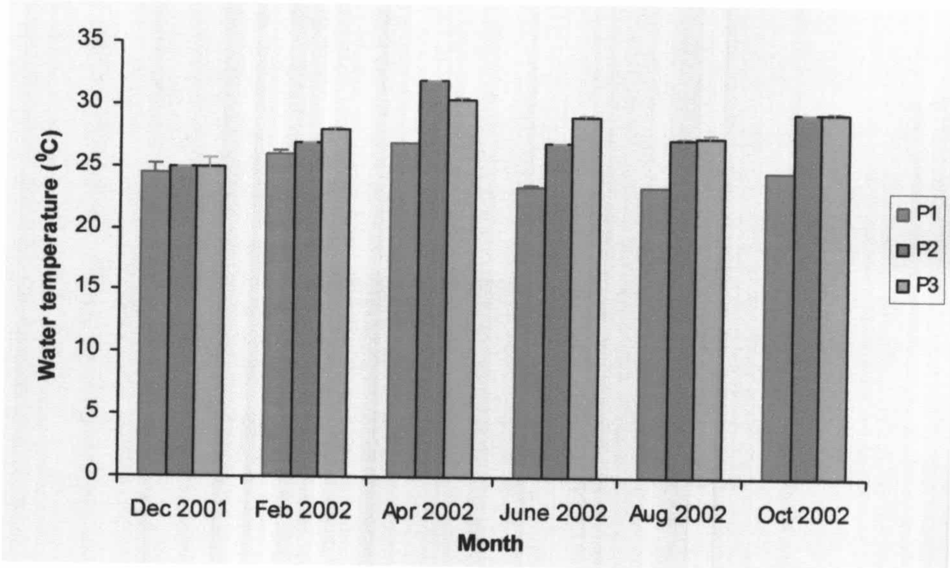


Figure 4.12 Average of water temperature in subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

4.3.1.4 Suspended Solid

The averages of suspended solid in three stations varied from 0.60 to 20.20 mg/l. The highest average of suspended solid was 20.20 mg/l at station P1 at the end of the wet season (October 2002) and the lowest average of suspended solid was 0.60 mg/l at station P3 at the end of the dry season (April 2002) (Figure 4.13).

The averages of suspended solid were high at the beginning of the dry season (December 2001). Then the values decreased in February and April 2002 at all stations. After that the values increased rapidly at the beginning of the wet season and remained high throughout the wet season, especially station P1. Station P1 located at the head water and has higher slope than station P2 and P3 (Royal Thai Survey Department, 1991). The flood flowed down into the river and increased turbidity from soil erosion. In addition, the area along the river banks was cultivated. Suspended solid in all three stations had tended to correlate to rain fall.

The averages of suspended solid were high in the wet season and were clearly different within the seasons at all stations in subsystem I. The increase in human activities, particularly urbanization and agriculture has led to increasing eutrophication; i.e. an increase of nutrients and a higher of suspended solid (Lundin and Linden, 1993) However, the first important reason of high suspended solid in upstream is the soil erosion (Odum, 1975; Wetzel, 2001).

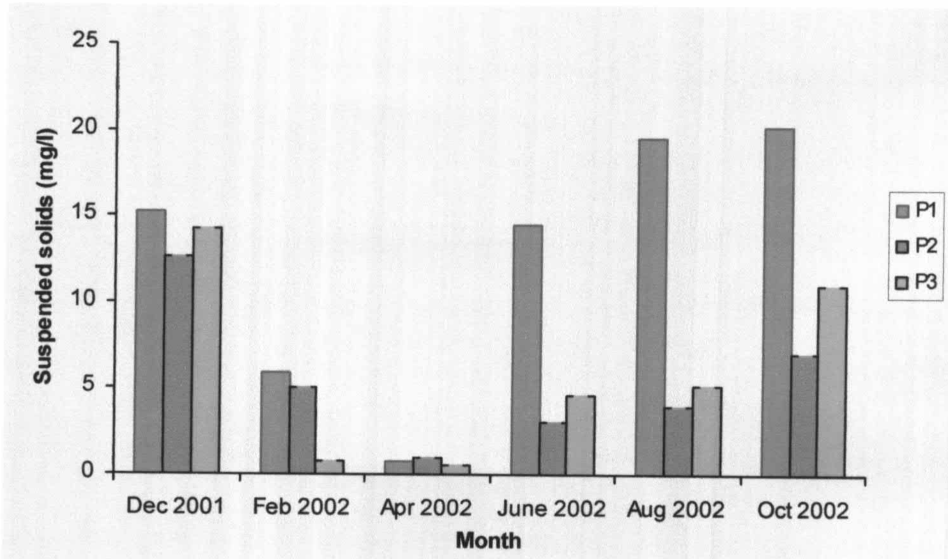


Figure 4.13 Average of suspended solid in subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

4.3.2 Chemical Parameters

The chemical parameters were measured along the station P1 to P3 from upstream until approaching to the inlet of Kaeng Krachan reservoir. They contained as the following:

4.3.2.1 pH

The averages of pH of the water in three stations varied from 6.40 ± 0.00 to 7.90 ± 0.00. The highest average of pH was 7.90 ± 0.00 at station P3 at the beginning of the dry season (December 2001) and the lowest average of pH was 6.40 ± 0.00 at station P2 at the end of the wet season (October 2002) (Figure 4.14). The pH of water showed small variation between in the wet and the dry seasons. However, the average of pH of water in station P2 was lower than station P1 and station P3 because the area of station P2 was an agricultural subwatershed and its flow was slower than the flows at station P1 and P3. The fertilize uses can affect to reduce the value of pH.

The average pH of water at station P1 was significantly different within the seasons at the $p = 0.05$ (Table 1 in Appendix E). However, the average pH of water in all stations correlated to the seasons but they were not significantly different in station P2 and P3 throughout the year. The pH values of all three stations in subsystem I were 6.4 to 7.9, which were similar to the natural waterbody of between 6.0 and 8.5 (Chapman, 1992). The pH of water can control the activity of living organisms in the water. The optimum pH levels that are suitable for living organisms in water are in a range from 6 to 8 (Gajaseni, 1996).

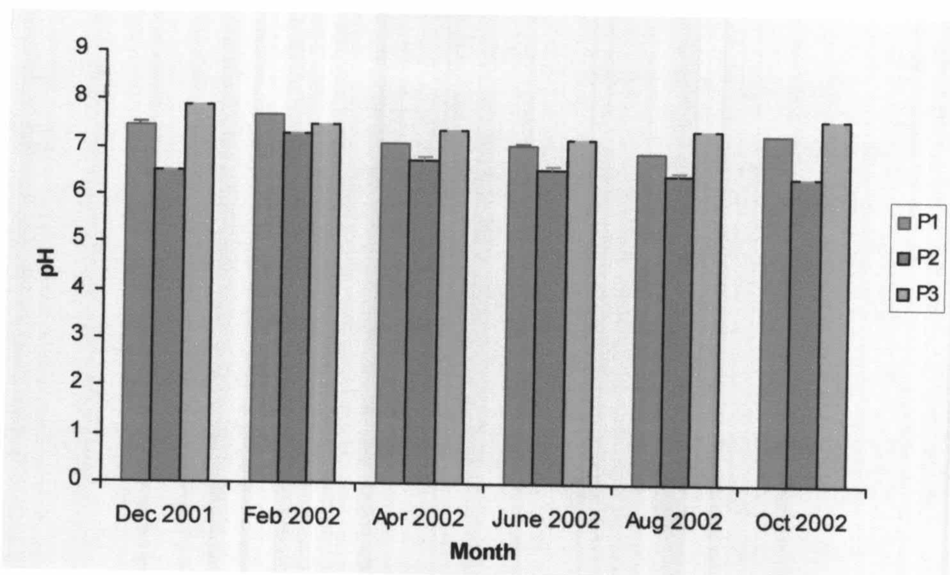


Figure 4.14 Average of pH in subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

4.3.2.2 Dissolved Oxygen

The averages of dissolved oxygen varied from 5.40 ± 0.00 to 8.80 ± 0.00 mg/l. The highest average of dissolved oxygen was 8.80 ± 0.00 mg/l at station P1 at the beginning of the dry season (December 2001) and the lowest average level of dissolved oxygen was 5.40 ± 0.00 mg/l at station P2 in the middle of the dry season (February 2002) (Figure 4.15). It was affected by flooding and related to suspended increment caused by high rainfall. Dissolved oxygen at station P2 and station P3 in the wet season slightly increased because of the higher flow in the rainy season. At station P2, the average of dissolved oxygen was lower than station P1 and station P3 throughout the year because the streamflow at station P2 (Mae Pradon Subwatershed) was lower than station P1 and P3. For station P1, dissolved oxygen values were high throughout the year because there was rainy all year (the interviews of local people).

Oxygen is essential to all forms of aquatic life and dissolved oxygen values depended on the physical, chemical and biological nature at each station. The average of dissolved oxygen of all three stations in subsystem I was between 6.3 to 8.8 mg/l which were higher than the general optimum of dissolved oxygen value. The dissolved oxygen, that is suitable for living organisms in water, is 5 mg/l (Gajaseni, 1996). In addition, most of the values of dissolved oxygen at all stations were not lower than the second class of surface water quality standard excepted at station P2 in February, 2002. Pollution Control Department (1997) assigns the second class of surface water quality standard must be $\geq$ 6 mg/l. The Pollution Control Department (2001) assigns that the water surface in Phetchaburi River was in the third class and the second class from the position of river mouth to 20 km the river mouth and 20 km to the Kaeng Krachan Reservoir, respectively. It included the area of upstream above the reservoir (station P3). Then it must be a cause of concern in the water quality at station P2 and P3.

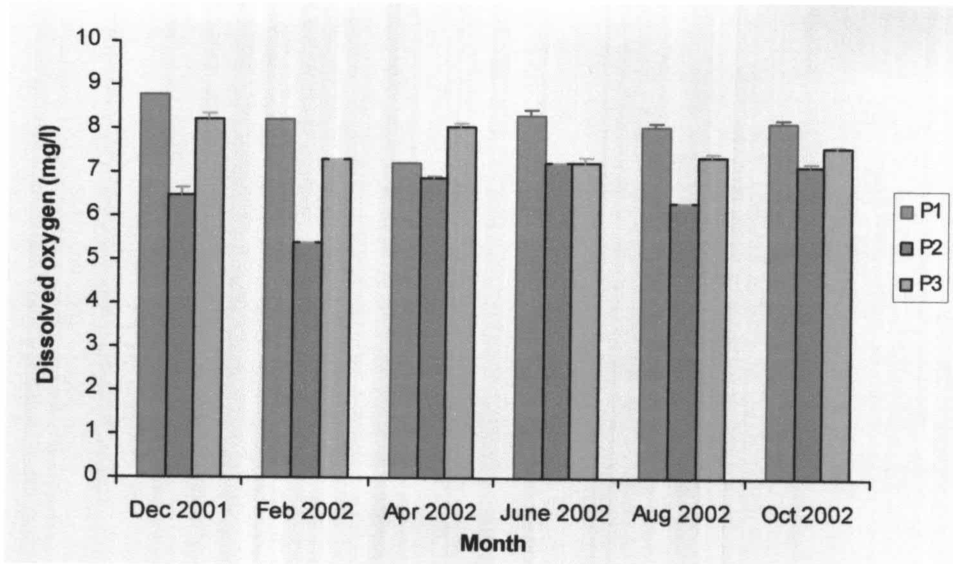


Figure 4.15 Average of dissolved oxygen in subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

4.3.2.3 Nitrate-Nitrogen

The averages of nitrate-nitrogen concentration varied from 0.55 ± 0.16 to 110.02 ± 0.09 ug/l. The highest average of this value was 110.02 ± 0.09 ug/l at station P1 in the middle of the wet season (August 2002) and the lowest was 0.55 ± 0.16 ug/l at station P3 at the end of the dry season (April 2002) (Figure 4.16). In the wet season, the water flow carried high nutrients into the river because of rainfall flushing nutrient from high land and agricultural areas along the river banks.

The nitrate-nitrogen concentration was high at station P1 (head water) and P2 (Mae Pradon Subwatershed). A river in primitive forest usually has high nitrate-nitrogen concentration and correlates to the wet season because of high rate of soil erosion. At station P3 which was located above the riverine zone of Kaeng Krachan reservoir, the nitrate-nitrogen concentration was decreased and different from station P1 and P2. Nutrients are increased in wider rivers and in riverine zones of reservoir and sedimentation after the low velocity (Wetzel, 2001). Station P2 was located in a small agricultural subwatershed, however its nitrate-nitrogen concentration was lower than station P1, especially in the dry season. Station P2 had suitable conditions for aquatic lives and they can use nutrients for their metabolism.

Although the nitrate-nitrogen concentration at station P3 was slightly different throughout the year and was lower than the values of station P1 and P2. The nitrate-nitrogen concentration of subsystem I (upstream watershed) was different significantly within the seasons at the $p = 0.05$ (Table 12 in Appendix E). The average of nitrate-nitrogen concentration did not exceed 5 mg/l that is the maximum figure set as the standard of surface water quality in Thailand (Pollution Control Department, 1997).

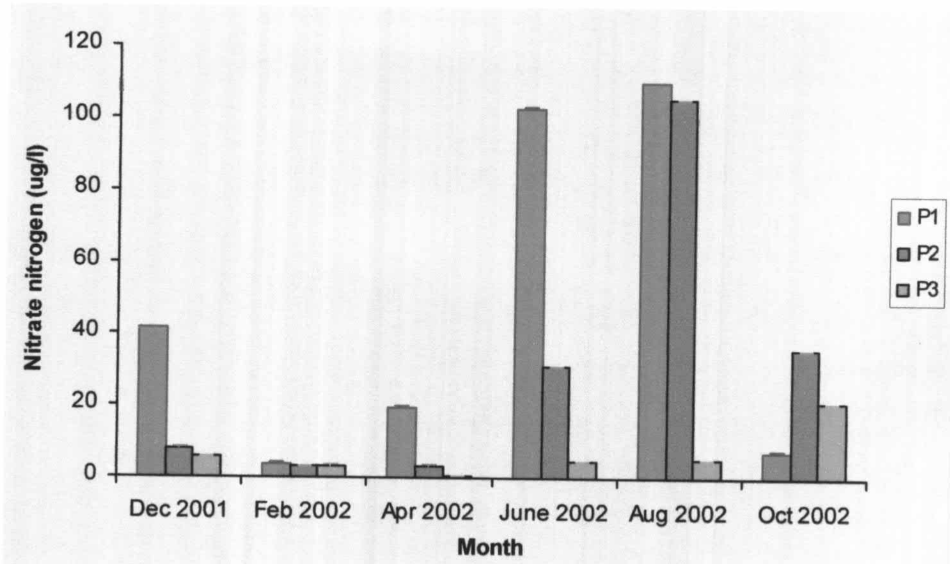


Figure 4.16 Average of nitrate-nitrogen in subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

4.3.2.4 Nitrite-Nitrogen

The averages of nitrite-nitrogen concentration ranged from 0.23 ± 0.00 to 3.17 ± 0.11 ug/l. The highest average of the value was 3.17 ± 0.11 ug/l at station P2 at the end of the wet season (October 2002) and the lowest was 0.23 ± 0.00 ug/l at station P3 at the beginning of the wet season (June 2002) (Figure 4.17).The nitrite-nitrogen concentrations were low throughout the investigation and the values had a positive correlation with suspended solid significantly at $p = 0.01$.

The nitrite-nitrogen concentration was very low throughout the year. Nitrite-nitrogen is one type of suspended solid and presents when the turbidity is high (Goldman and

Horne, 1994). In addition, nitrite-nitrogen concentration at station P2 (the small agricultural subwatershed) was higher than other stations throughout the investigation. It might be from fertilizing use in agricultural areas along the river banks.

The nitrite-nitrogen concentration of subsystem I (upstream watershed) was low at all three stations throughout the year and was not different significantly within the seasons.

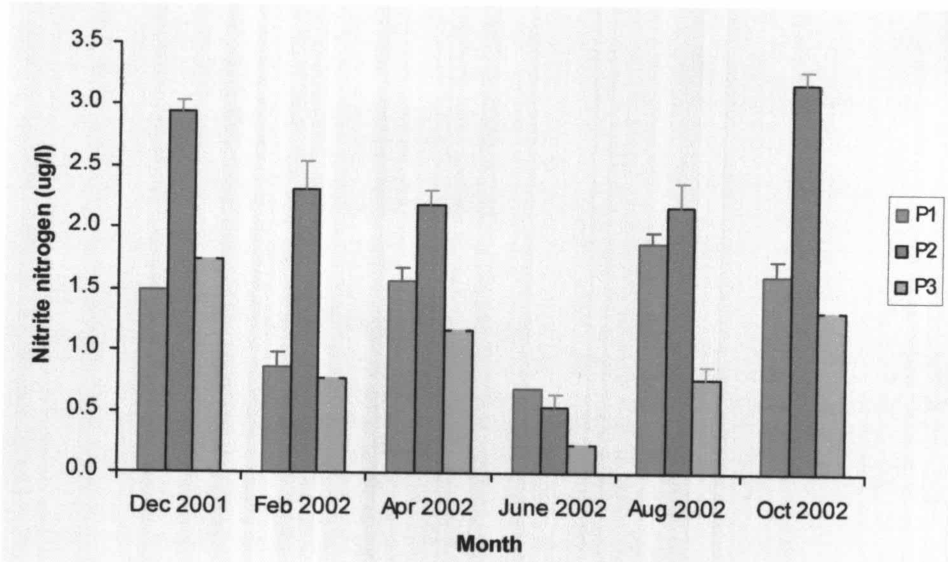


Figure 4.17 Average of nitrite-nitrogen in subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

4.3.2.5 Ammonium-Nitrogen

The averages of ammonium-nitrogen concentration varied from ND to 9.76 ± 0.00 ug/l. The highest average of ammonium-nitrogen concentration was 9.76 ± 0.00 ug/l at station P2 in the middle of the wet season (August 2002) and the lowest value could not be detected at all three stations in the middle of the dry season (February 2002) nor could it be detected at station P1 and P3 in the wet season (June and August 2002) (Figure 4.18). The concentrations were low throughout the investigation.

The ammonium-nitrogen concentration of station P2 was higher than at station P1 and P3. Station P2 was located in an agricultural subwatershed in which there was high use of fertilizers (the field notation). The bottom of the river basin was clay so the ammonium-nitrogen came from the digestion process of bacteria at the bottom (Wetzel, 2001). In addition, the waterbody received ammonium-nitrogen from polluted water that washed down the nutrients from the agricultural land (Strange *et al.*, 1999). This study found that the ammonium-nitrogen concentrations at all stations did not exceed 500 ug/l, that is the maximum figure set as the standard of surface water quality in Thailand (Pollution Control Department, 1997). However, it must be a cause for concern that the ammonium-nitrogen concentration at station P2 which is upstream of the watershed.

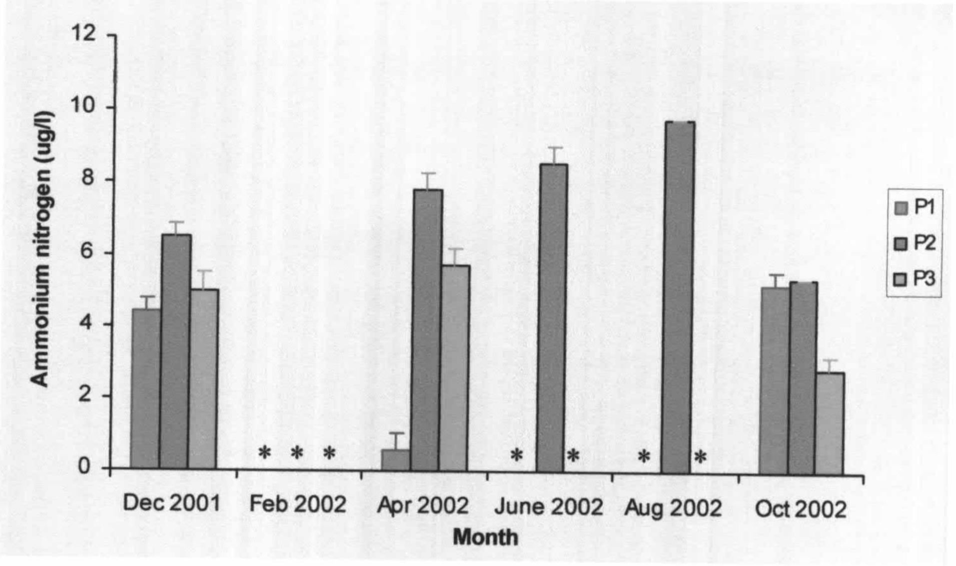


Figure 4.18 Average of ammonium-nitrogen in subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir* = could not be detected

4.3.2.6 Phosphate-Phosphorus

The averages of Phosphate-phosphorus concentration ranged from ND to 26.35 ± 0.77 ug/l. The highest concentration was 26.35 ± 0.77 ug/l at station P2 in the middle of the wet season (August 2002). Phosphate-phosphorus concentration could not be detected at any of the three stations at the end of the dry season (April 2002) and also could not be detected at station P2 at the beginning of the dry season (December 2001) (Figure 4.19). The value of Phosphate-phosphorus was low in the dry season. Then the concentration increased in the wet season because of high sediment loading that washed down from the land into the rivers. Phosphorus is essential for the growth of organisms and can limit the primary productivity of a waterbody.

The Phosphate-phosphorus concentrations of all stations were significantly different within the seasons at p = 0.05 (Table 2 and Table 3 in Appendix E). On the other hand, this value at station P1 was not different within seasons. It can show that station P1 is located in the primitive forest at head water of the watershed. In addition, Phosphate-phosphorus concentration was very low in the natural surface water of river (Wetzel, 2001). While at station P2 and P3, the government permits agriculturer to use fertilizers. This was the cause of the increased levels of Phosphate-phosphorus concentration in the wet season in station P2 and station P3 by washing from agricultural areas. However, the Phosphate-phosphorus in subsystem I (upstream watershed) was different significantly within the seasons at the p = 0.05 (Table 12 in Appendix E).

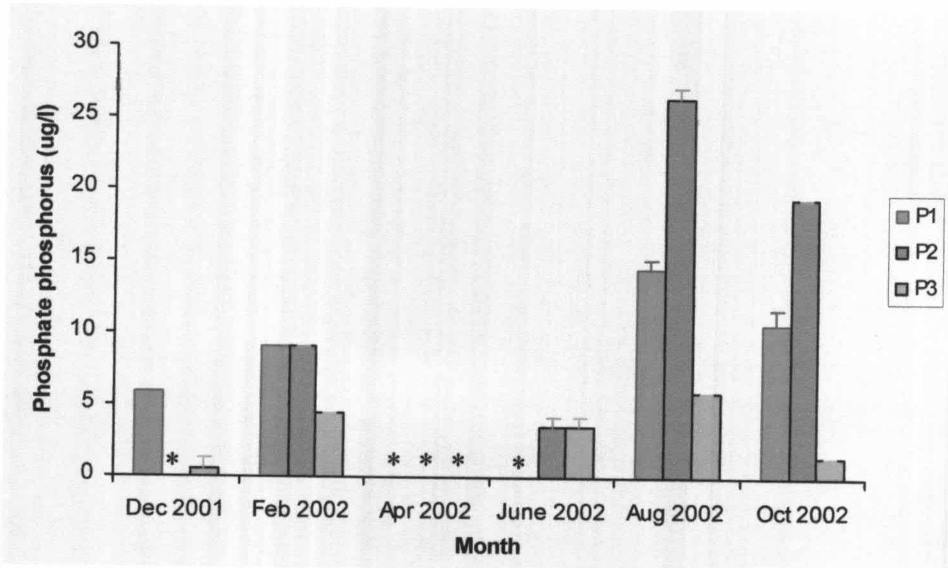


Figure 4.19 Average of phosphate-phosphorus in subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir, * = could not be detected

4.3.2.7 Silica-Silicon

The averages of silica-silicon concentration ranged from 2.80 ± 0.03 to 14.10 ± 0.05 mg/l. The highest average of this value was 14.10 ± 0.05 mg/l at station P2 at the end of the wet season (October 2002) and the lowest value was 2.80 ± 0.03 mg/l at station P2 at the end of the dry season (April 2001) (Figure 4.20).

The silica-silicon concentration of drainage to natural water is less variable than many of the other major inorganic constituents (Wetzel, 2001). The world average of silica is about 13 mg/l with relatively little variation among the continents (Wetzel, 1983). Silica is one of the nutrients that is very important for diatom group and it is usually a high number in the lotic ecosystem. This study found that silica was enriched in all stations. However, it was slightly decreased in the dry season, especially in April. Silica-silicon concentration had tended to be increased from soil and rock weathering. The at all three stations were different significantly within the seasons at p = 0.05 (Table 1, 2 and 3 in Appendix E).

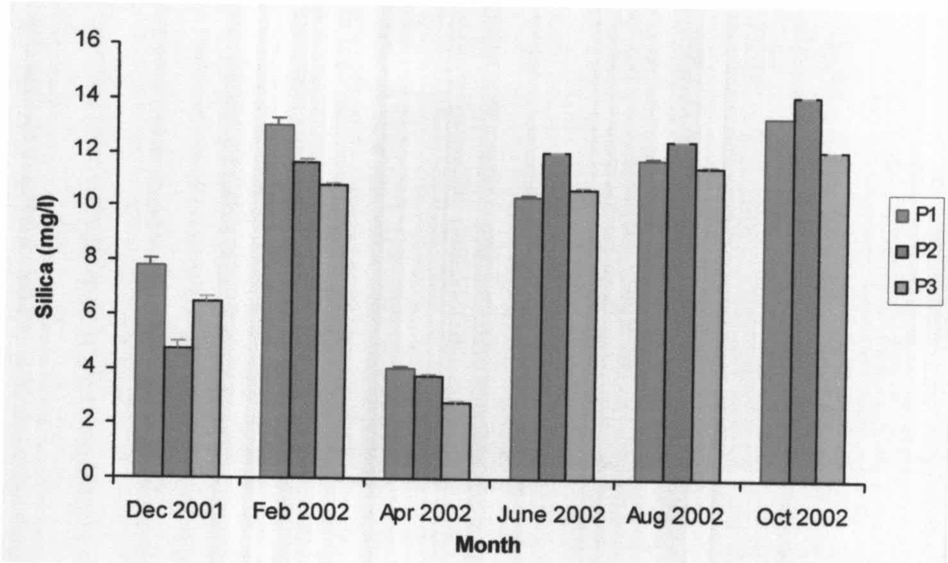


Figure 4.20 Average of silica-silicon concentration in subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

4.3.3 Biological Parameters

For biological parameter, phytoplankton is very important to an aquatic ecosystem. Therefore, phytoplankton dynamics are examined in order to analyze the relationship to ecological parameters due to seasonal variation as well as land use activities. Thus, the species composition, phytoplankton density and chlorophyll *a* concentration were indicated as follow;

4.3.3.1 Species Composition

A study of biodiversity of phytoplankton was conducted in order to analyze the existing ecological condition of the subsystem I (upstream) from December 2001 to October 2002. Phytoplankton were found and were classified into 5 divisions, 5 classes 10 orders, 24 families, 37 genera and 41 species including 4 unidentified species. Following Rott's 1981 classifications, this investigation found that the total phytoplankton consisted of 6 groups in subsystem I. The Diatomophyceae was the most abundant species of phytoplankton with 20 species. There were 8 species of Cyanophyceae and 2 species of Dinophyceae. Eight species of Chlorophyceae were found. Two species of Zygnemaphyceae were found and only one species of Euglenophyceae was found (Table 4.2).

When compare to other researches that studied in upstream areas, this study was the same as Peerapornpisal, Pektong, Waiyaka and Promkutkew (2000) – which reported that diatom was the most abundant majority of phytoplankton in Mae Sa Stream, Doi Suthep-Pui National Park, Chiang Mai. Furthermore, Noinamsai (2000) reported that diatom was the major group in the lotic ecosystem at head water of the Lam Phra Phloeng Watershed and that the most important influence on phytoplankton biodiversity was temperature in the watershed.

Table 4.2 List of species of phytoplankton survey in subsystem I

Phytoplankton species		
Cyanophyceae	*Anabaena* sp.1	*
	Cylindrospermopsis sp.	*
	Lyngbya sp.	*
	Merismopedia sp.	*
	Microcystis aeruginosa	*
	Oscillatoria sp.	*
	Spirulina sp.	**
	Unidentified 4	**
Dinophyceae	*Ceratium* sp.	*
	Peridinium sp.	*
Diatomophyceae	*Achananthes* sp.	*
	Aulacoseira sp.	*
	Bacillaria sp.	*
	Bacteriastrum sp.	*
	Chaetoceros sp.1	*
	Coscinodiscus sp.	***
	Cyclotella sp.	*
	Cymbella sp.	*
	Epithemia sp.	*
	Fragilaria sp.1	*
	Gomphonema sp.	*
	Gyrosigma sp.	*
	Navicula sp.1	*
	Nitzschia sp.1	*
	Surirella sp.	*
	Synedra sp.	*
	Tabellaria sp.	*
	Thallassiosira sp.	*
	Unidentified 1	*
	Unidentified 2	*
Chlorophyceae	*Ankistrodesmus* sp.	*
	Botryococcus braunii	***
	Crucigenia sp.	*
	Pediastrum sp.1	*
	Scenedesmus sp.1	*
	Spirogyra sp.	*
	Staurodesmus sp.	*
	Unidentified 3	*
Zygnemaphyceae	*Cosmarium* sp.1	*
	Staurastrum sp.1	*
Euglenophyceae	*Phacus* sp.1	*

Note: Unit of phytoplankton density, * = cell, ** = filament, *** = colony

4.3.3.2 Dominant Species and Phytoplankton Diversity

Subsystem I (upstream) of the Phetchaburi Watershed had 3 stations. The dominant species of station P1 (the primitive forest area at head water, Phetchaburi River) were *Oscillatoria* sp., *Navicula* sp.1, *Tabellaria* sp. and *Surirella* sp. The dominant species of station P2 (agricultural area at head water, Mae Pradon Subwatershed, Phetchaburi Watershed) were *Oscillatoria* sp., *Peridinium* sp. and *Nitzschia* sp.1. The dominant species of station P3 (agricultural area at headwater, Phetchaburi River) were *Microcystis aeruginosa*, *Oscillatoria* sp., *Peridinium* sp., *Navicula* sp.1 and *Botryococcus braunii* The dominant phytoplankton species were shown in Figure 4.21.

The numbers of phytoplankton species were slightly different within the seasons (Figure 4.22). Phytoplankton of station P1 (the primitive forest area at headwater, Phetchaburi River) were found 31 species in the dry season. On the other hand, in the wet season brought a high level of suspended solid that affected phytoplankton growth. Station P2 (agricultural area at head water, Mae Pradon Subwatershed, Phetchaburi Watershed) had a lower number of at 27. species. This area had high turbidity and low velocity. However, its chlorophyll *a* concentration was higher than in station P1 because there was agricultural area along the river banks. In station P3 (agricultural area at headwater, Phetchaburi River) it was different with the various seasons. The number of species in the dry season was 29 species that was higher than in the wet season. It might have affected the phytoplankton bloom.

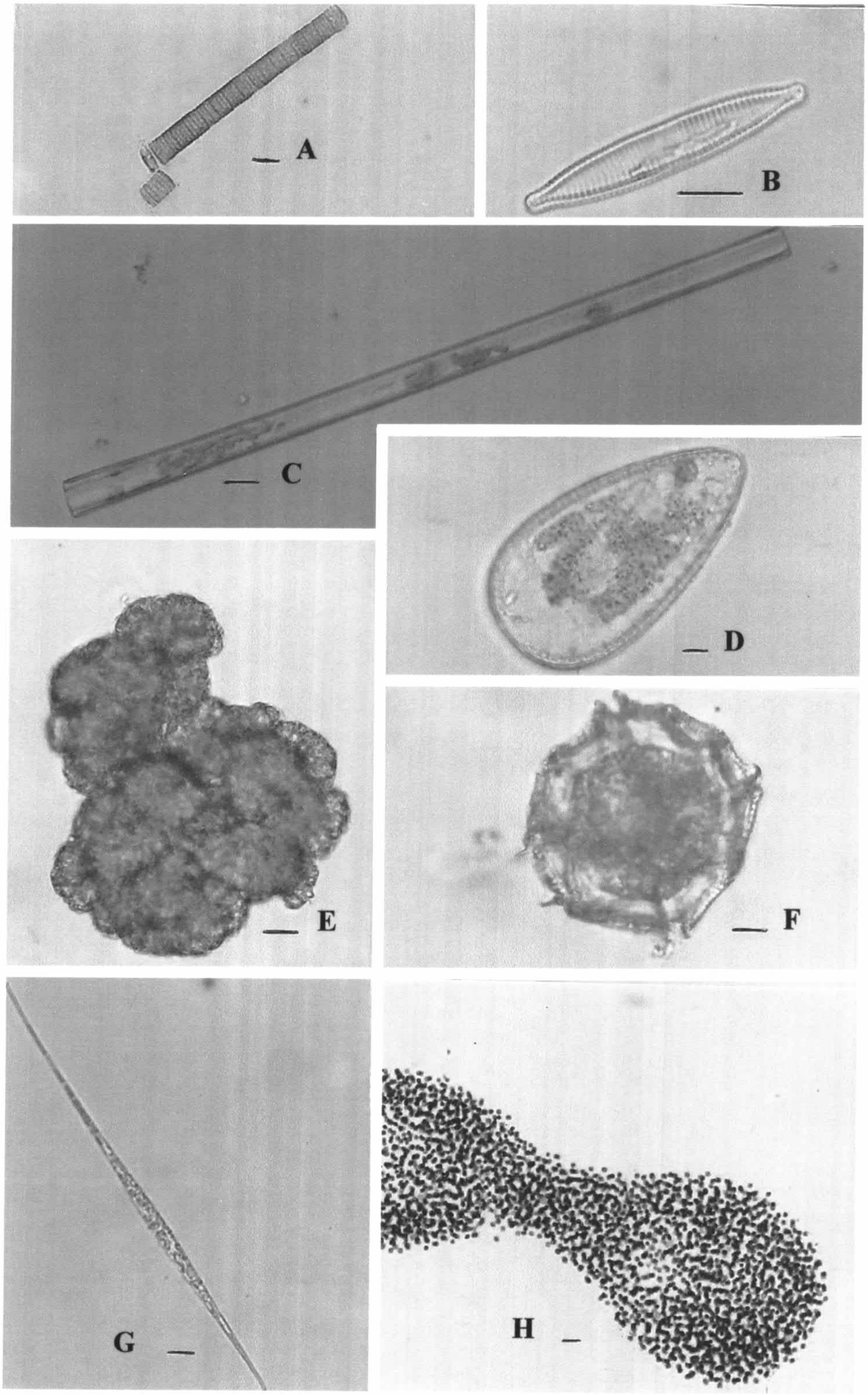


Figure 4.21 Dominant phytoplankton species in subsystem I (upstream) of Phetchaburi Watershed, *Oscillatoria* sp. (A), *Navicula* sp. (B), *Tabellaria* sp. (C), *Surirella* sp. (D), *Botryococcus braunii* (E), *Peridinium* sp. (F), *Nitzschia* sp.1 (G) and *Microcystis aeruginosa* (H), scale bar — = 10 micron

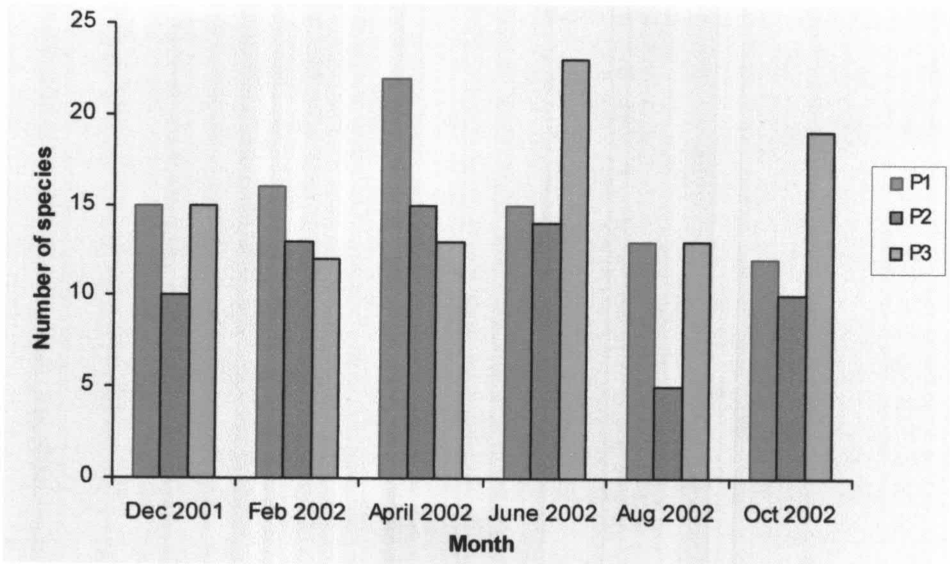


Figure 4.22 Number of phytoplankton species of subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

4.3.3.3 Phytoplankton Density in Subsystem I (Upstream) of Phetchaburi Watershed

Table 4.3 and Figure 4.23 shows the total density of phytoplankton in subsystem I (upstream) that consisted of three stations. Phytoplankton density station P1 (the primitive forest area at head water, Phetchaburi River) ranged from $314 \times 10^6 \pm 13 \times 10^6$ to $149.20 \times 10^8 \pm 9.66 \times 10^8$ unit/m^3 at. At the head water area or the primitive forest, there is usually a low quantity of aquatic life because it has low nutrient concentration in the dry season and is disturbed by a high flow of water in the wet season. This was contrasted at station P2 (agricultural area at downstream, Mae Pradon Subwatershed) in which the density was ranged from $34 \times 10^6 \pm 2 \times 10^6$ to $179.11 \times 10^8 \pm 14 \times 10^8$ unit/m^3 At station P2, although it was located at the upstream, it has an agricultural area along the river banks, and it also had high nutrient concentration. Then phytoplankton density at station P2 was higher than at station P1. However, in August it was rain while we were collecting the samples. Then both of the diversity and density of phytoplankton were low. In addition its chlorophyll *a* was also low. At station P3 (agricultural area at upstream, Phetchaburi River), phytoplankton density was increased from from $375.36 \times 10^8 \pm 4 \times 10^8$ to $646.4377 \times 10^{11} \pm 6.44370 \times 10^{11}$ unit/m^3 unit/m^3. At station P3, it was located above the Kaeng

Krachan Reservoir, and received nutrients from upstream. In addition, there were many agricultural areas along the river bank. These areas had definite high nutrient concentrations (Royal Forest Department, 1994). On the other hand, the slope of station P3 is less than station P1 (Royal Thai Survey Department, 1991), then the water flowed slower than station P1, so it was suitable for phytoplankton growth. In the other word, station P3 has the ecological conditions linked the lentic ecosystem. Furthermore, there was phytoplankton bloom throughout in the wet season (Figure 4.23 C), which was the same period of the bloom in the Kaeng Krachan Reservoir. Diatoms are usually dominant of plankton in a large river along with, particularly in summer, a variety of green algae, many flagellates, chrysophytes and cyanobacteria are vigorous; these groups can increase in areas where currents are reducing (Wetzel, 2001).

Table 4.3 Phytoplankton density in subsystem I (upstream) of Phetchaburi Watershed

Month	station	Total of Phytoplankton density x 10^6 (unit/m^3)
Dec-01	P1	3573 ± 323
	P2	17912 ± 1410
	P3	25530 ± 1615
Feb-02	P1	4894 ± 351
	P2	6154 ± 445
	P3	7536 ± 400
Apr-02	P1	14920 ± 967
	P2	15815 ± 1154
	P3	6977 ± 557
Jun-02	P1	4892 ± 288
	P2	3873 ± 237
	P3	1426572 ± 107484
Aug-02	P1	314 ± 14
	P2	34 ± 3
	P3	945052 ± 82571
Oct-02	P1	1983 ± 106
	P2	1393 ± 84
	P3	6464378 ± 644371

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

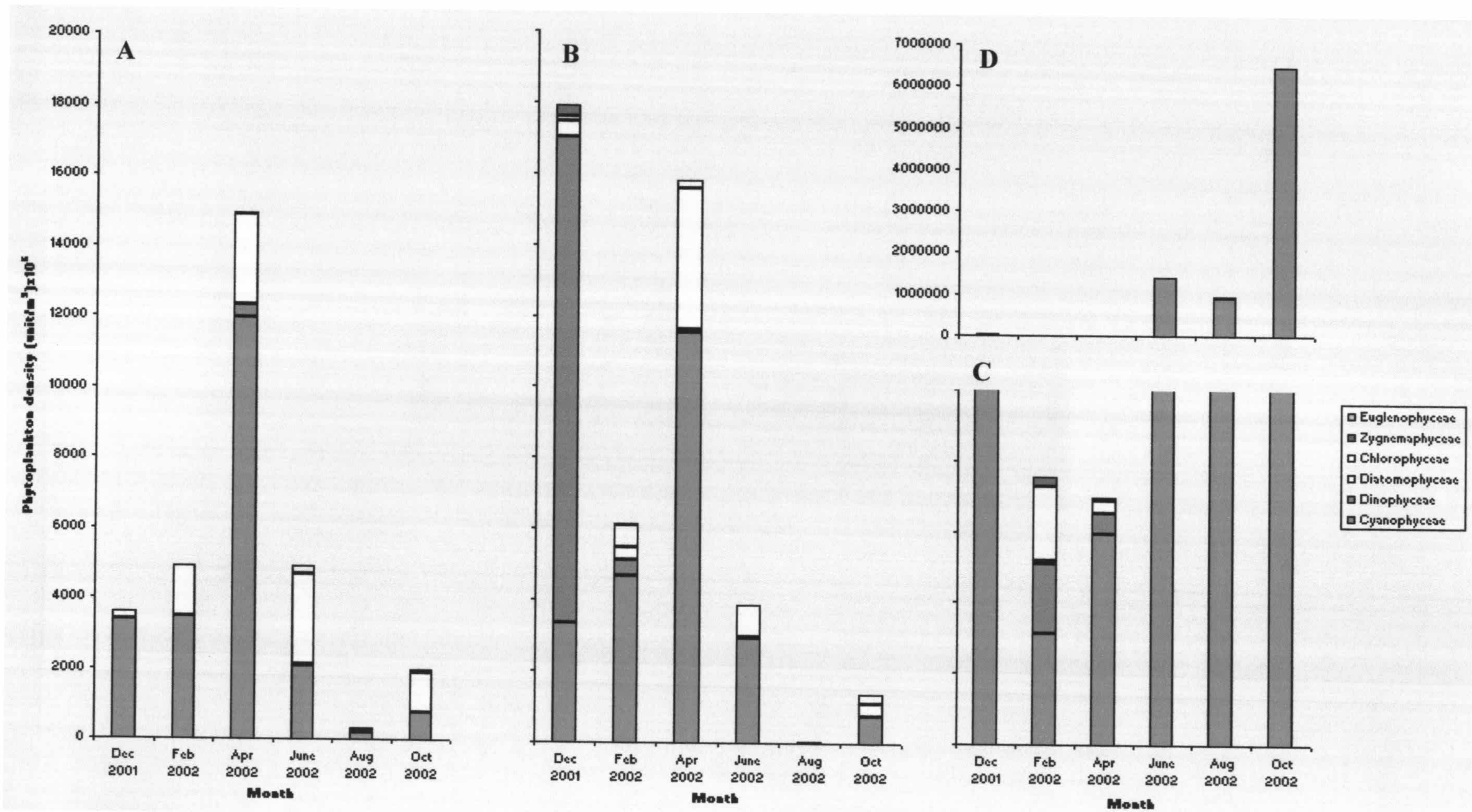


Figure 4.23 Seasonal variation of phytoplankton density (unit/m^3) and portion of the taxonomic groups in station P1 (A), station P2 (B), station P3 (full scale) (C) and station P3 (reduced scale) (D)

4.3.3.4 Chlorophyll *a*

The averages of chlorophyll *a* concentration ranged from 0.35 ± 0.00 to 20.39 ± 0.72 mg/m^3. The highest average of chlorophyll *a* concentration was 20.39 ± 0.72 mg/m^3 at station P3 at the end of the wet season (October 2002) and the lowest was 0.35 ± 0.00 mg/m^3 at station P1 at the beginning of the wet season (June 2002) (Figure 4.24).

At the beginning of the wet season, there were phytoplankton blooms and both chlorophyll *a* concentration and phytoplankton density at station P3 increased rapidly until October, 2002. Polution Control Department (2002) reported that chlorophyll *a* concentration in the area of station P3 ranged from 0.175 to 12.124 mg/m^3. This contrasted to station P1 and P2. Both chlorophyll *a* concentration and phytoplankton density of station P1 and P2 were high in the dry season and decreased in the wet season. In addition both of chlorophyll *a* concentration at station P1 and P2 were significantly different within the seasons at the $p = 0.05$ (Table 1 and 2 in Appendix E). Chlorophyll *a* is a major pigment in every kind of phytoplankton cell and it is important in photosynthesis. For this study, it was found that the chlorophyll *a* concentration at station P3 had a positive correlation with phytoplankton density (Table 16 in Appendix E). Station P3 was located above the riverine zone of the Kaeng Krachan Reservoir then the water current was slow down. This zone has nutrient enriches, especially in the wet season. These conditions are suitable for phytoplankton growth. On the other hand, station P1 had very high flow in the wet season then it was not good condition for phytoplankton growth.

However, chlorophyll *a* concentration at station P2 in the Mae Pradon River and station P3 in the Phetchaburi River were very high for a river ecosystem These areas are in upstream of the watershed. Then the fertilizer uses in agriculture must be controled in order to reduce the contamination into the river.

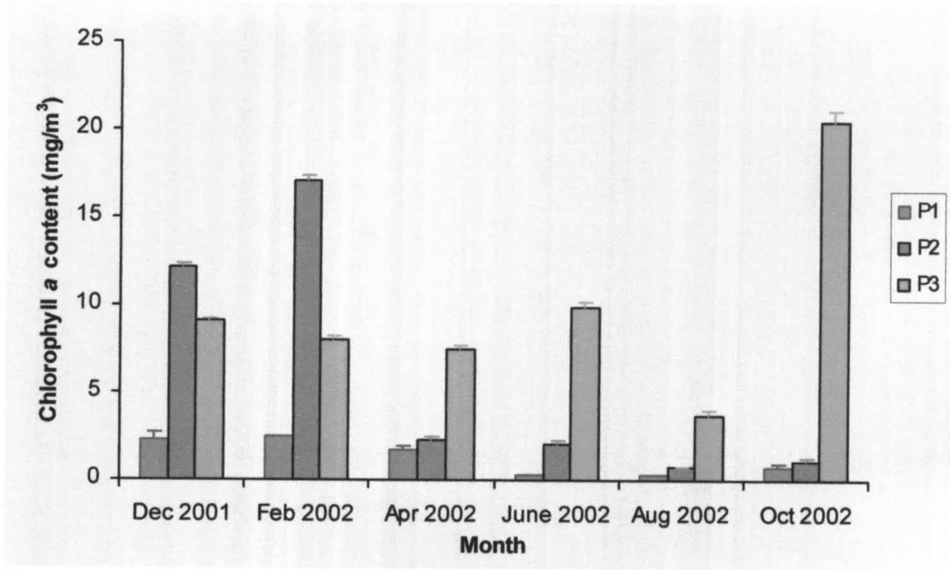


Figure 4.24 Average of chlorophyll *a* concentration in subsystem I (upstream) of Phetchaburi Watershed

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

4.3.3.5 Shannon-Wiener's Index of phytoplankton in subsystem I

Shannon-Wiener's Index of phytoplankton of three stations in subsystem I had tended to be correlated to the seasons (Table 4.4). Shannon-Wiener's Index ranged from 0.467 to 2.118. The values of the index at station P1 and P2 in the wet season were higher than in the dry season. Although the numbers of species were low, smaller numbers of density were the reason for increasing the values of the Shannon-Wiener's Index. Polution Control Department (2002) reported that the phytoplankton diversity index at Ban Pratoo Pee (station P3) was 0.992. This study found that the value of the diversity index at station P3 was 0.784, and the value of the index in the dry season was higher than in the wet season because of the blooming of cyanobacteria in the wet season. Besides, the Shannon-Wiener's Index in the primitive area at the head water (station P1) was higher than in the agricultural areas (station P2 and P3). These areas were highly density of phytoplankton.

Table 4.4 Shannon-Wiener's Index of phytoplankton in subsystem I (upstream) of Phetchaburi Watershed

Shannon-Wiener's Index							
Station	Dec-01	Feb-02	Apr-02	Jun-02	Aug-02	Oct-02	Annual year
P1	0.572	1.09	1.265	1.301	2.118	1.536	1.314
P2	0.737	1.113	0.98	1.344	1.421	1.406	1.176
P3	1.13	1.482	0.848	0.719	0.467	0.059	0.784

Note: P1 = the primitive forest area at head water, P2 = agricultural area, Mae Pradon Subwatershed, P3 = agricultural area above Kaeng Krachan Reservoir

This study was different from the study of the phytoplankton diversity in Lam Phra Phloeng Watershed. Noinumsai (2000) reported that the average of the phytoplankton Shannon-Wiener's Index at the head water of Lam Phra Phloeng Watershed was 0.5044 $\pm$ 0.54. He also found that the Shannon-Wiener's Index in the agricultural area was the highest value at 0.7334 and the head water area was the lowest value at 0.3003. In this study we found that the average value of the diversity index in head water area (station P1) was higher than in the agricultural areas (station P2 and P3), especially in the wet season. The first important reason might be the amount of cyanobacteria of station P2 in the dry season and station P3 in the wet season.

4.3.4 The Correlation between Ecological Parameters in Subsystem I (Upstream) of Phetchaburi Watershed

According to the investigation in subsystem I (upstream), there were different correlation between the ecological parameters of all three stations. At station P1 (the primitive forest area at head water), the phytoplankton density and chlorophyll *a* concentration had a positive correlation to water temperature significantly at the p = 0.05 and 0.01, respectively (Table 14 in Appendix E). Phytoplankton density and chlorophyll *a* concentration had a negative correlation with most nutrients. In addition, phytoplankton density had a negative correlation to suspended solid significantly at the p = 0.05. Station P1 was located at the head water of the watershed. It has high slope so that the effect was to increase the rate of soil erosion, especially in the rainy season. On the other hand, the high velocity is not suitable for phytoplankton growth. All nutrients had tended to correlate to suspended solid but not significantly. However, phytoplankton density had tended to correlate to chlorophyll *a* concentration. In addition, phytoplankton density and chlorophyll *a* concentration were significantly different within the seasons at the $p = 0.05$ (Table 1 in Appendix E).

At station P2 (Mae Pradon Subwatershed), phytoplankton density and chlorophyll *a* concentration had a negative correlation to nitrate-nitrogen concentration significantly at the $p = 0.01$ and 0.001, respectively (Table 15 in Appendix E). In addition, phytoplankton density and chlorophyll *a* concentration had a negative correlation to Phosphate-phosphorus concentration significantly at the $p = 0.0001$ and 0.05, respectively. The correlation between phytoplankton density and nutrients at station P2 was the same as station P1. However, the reasons of the correlation were different. In station P2, the velocity was slower than station P1 and the waterbody of the river was smaller than station P1. There were high nutrients, the water was very turbid (field notation) and transparency depth was low. In addition, it was raining (the field trip 5th in the wet season) while we collected data at station P2. This might decrease phytoplankton density from the water surface, then chlorophyll *a* concentration was also low. However, the chlorophyll *a* concentration at this station was very high for the river ecosystem, especially in the dry season. Phytoplankton had tended to be bloom and could affect to other aquatic lives.

At station P3 (agricultural area at headwater, Phetchaburi River), the phytoplankton density and chlorophyll *a* concentration had a positive correlation to nitrate-nitrogen significantly at the $p = 0.0001$ (Table 16 in Appendix E). Phytoplankton density had also positive correlation to silica-silicon concentration significantly at the $p = 0.05$. Although station P3 was located in the river, it was like the lentic ecosystem because it was located above the Kaeng Krachan Reservoir. It was low velocity and high water volume. In addition, the water washed nutrients down from the upstream and agricultural areas along the river banks. These were suitable conditions for phytoplankton growth, especially in the wet season. Although it might have high turbidity, after the sedimentation, phytoplankton grew rapidly and bloomed in the wet season. Phytoplankton density had a positive correlation to chlorophyll *a* concentration significantly at the $p = 0.0001$ (Table 16 in Appendix E). Both of phytoplankton density and chlorophyll *a* concentration were significantly different within the seasons at the $p = 0.05$ (Table 3 in Appendix E).

Based on this study, the water quality in the areas of subsystem I classified by standard surface water quality in Thailand was found to be the first to second category and was relatively suitable for fisheries and water supplies when properly treated (Pollution Control Department, 1997). However, it must be concern the water qualities at station P2 and P3. For station P2, it had agricultural area along the river bank and its streamflow was slow. Then there were high nutrient concentrations because of fertilized uses. Especially, it was phytoplankton bloom in the dry season. This condition indicated the river area was not good ecological condition. For station P3, its ecological conditions liked the condition in the Kaeng Krachan Reservoir. Then the area at station P3 and the Kaeng Krachan Reservoir were phytoplankton blooms in the wet season. Although they were not severe, it may be more severe situation in the future.

4.4 Ecological Relationships of Subsystem II

As results, the ecological parameters as physico-chemical parameters were shown in relation to seasonal variation and locality in subsystem II (Kaeng Krachan Reservoir). This subsystem was divided into 3 substations such as, substation P4a located at the upstream water inlet, substation P4b was located at the water in the reservoir, that was near the area of a big community and substation P4c was located at the water outlet from the reservoir downstream. The reservoir received water from upstream that had agricultural areas along the river banks. In addition, there were agricultural areas surrounding the reservoir and about three hundred cattle in the riverine zone (substation P4a). There were a hundred families near substation P4a. In fact, most areas of this subsystem is in Kaeng Krachan National Park and the areas are controlled by the office of Kaeng Krachan National Park and the Department of Irrigation.

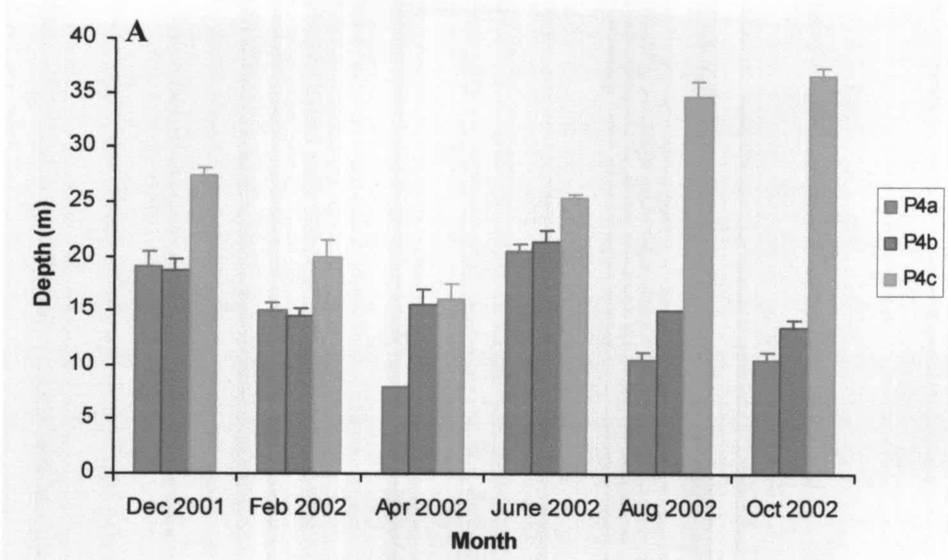
4.4.1 Physical Parameters

The physical parameters were measured at three substations in Kaeng Krachan Reservoir. They contained as the following:

4.4.1.1 Depth

The averages of water depth of three substations in the reservoir varied from 8.00 ± 0.00 to 36.50 ± 0.71 metres. The highest average of the water depth was 36.50 ± 0.71 metres at the substation P4c at the end of the wet season (October 2002) and the lowest average was 8.00 ± 0.00 metres at substation P4a at the end of the dry season (April 2002) (Figure 4.25 A). Kaeng Krachan Reservoir was an inlet area so it was not smooth and the depths were different in each substation especially in the wet season. "*Kaeng*" means the area of water where the flow is rapid and its bottom is rough, so it may have small islands in the dry season. Substation P4a was located at the riverine zone of the reservoir; then the depth of water was lower than other substations in the reservoir. In addition, this zone had high turbid because of streamflow from upstream (Wetzel, 2001).

On the other hand, substation P4c was located in front of the dam. That is the deepest point of the reservoir. Then the water level was higher than other substations. In addition, the water depth of substation P4c significantly differed from other substations at the $p = 0.05$ (Table 4.1 in Appendix E). However, the water depth at all three substations in the reservoir related to the seasons and the total water volume in the reservoir (Figure 4.25 B), especially substation P4c. In the year 2002 that was the period of this study the rainfall was higher than in the year 2001 and 2003 (before August). However, the Department of Meteorology reported that the water level did not exeed the capacity point of the dam.



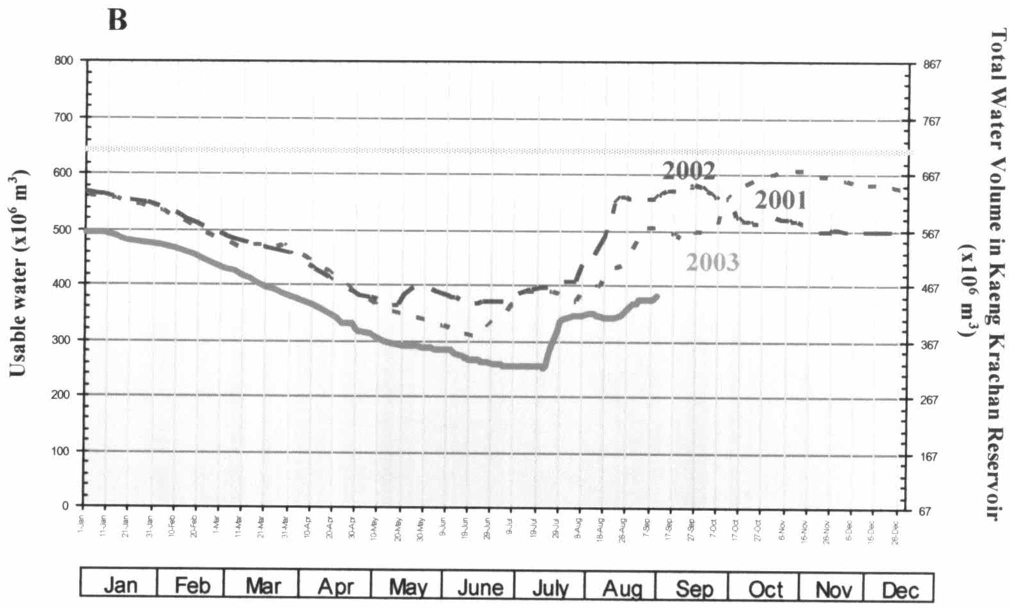


Figure 4.25 Average of depth in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed (A) and water volume in Kaeng Krachan Reservoir in 2001 - 2003 (B)

Source: Department of Meteorology

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream

4.4.1.2 Transparency Depth

The averages of transparency depth varied from 0.95 ± 0.07 to 2.45 ± 0.07 metres due to seasonal variation. The highest average of transparency depth was 2.45 ± 0.07

metres at substation P4b in the middle of the dry season (February 2002) and the lowest average of transparency depth was 0.95 ± 0.07 metres at substation P4a at the beginning of the dry and the wet seasons (December 2001 and June 2002) (Figure 4.26).

Substation P4a was located in the riverine zone and had high turbidity because of streamflow from upstream, so transparency depth at this substation was lower than other substations. In fact, the flood in the wet season of the year 2001 reduced the transparency depth in December, 2001 in the reservoir. In addition, transparency depth at all substations decreased in the wet season by the turbid water and this might affect to increase phytoplankton biovolume in the reservoir.

Transparency depth was different significantly within the seasons at $p = 0.05$ (Table 4.2 in Appendix E). On the other hand, transparency depth had a negative correlation with phytoplankton biovolume at $p = 0.05$ (Table 17 in Appendix E). Transparency depth changes with quantity of phytoplankton and inorganic substances in the water resource (Gajaseni, 1996). This study found that the phytoplankton bloomed from the late of the dry season thoughtout all the wet season.

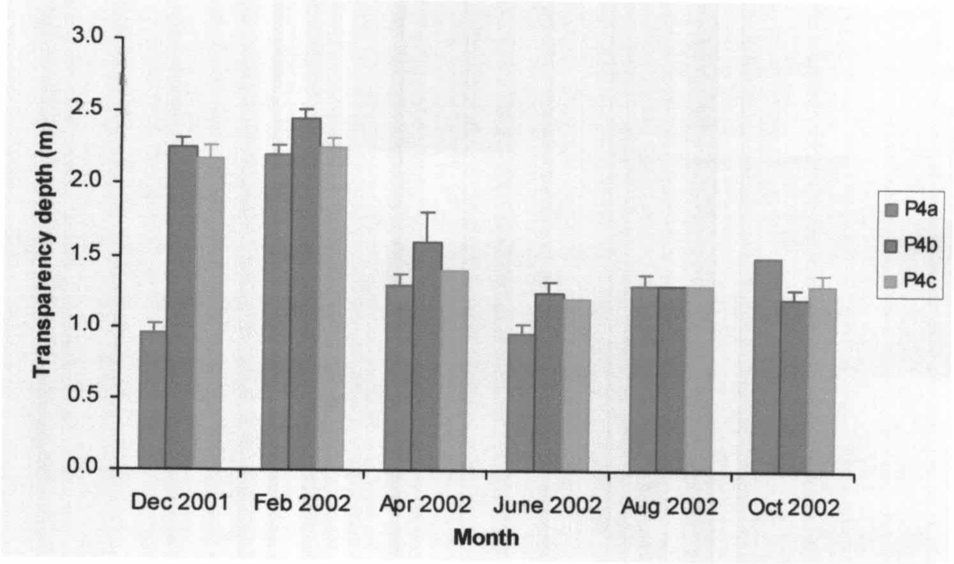


Figure 4.26 Average of transparency depth in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream

4.4.1.3 Water Temperature

The changes in water temperature related to the seasons. The averages of water temperature ranged from 24.00 ± 0.00 °C to 32.00 ± 0.00 °C. The highest average of water temperature was 32.00 ± 0.00 °C at substation P4c at the end of the dry season (April 2002) and the lowest average of water temperature was 24.00 ± 0.00 °C at substation P4c at the beginning of the dry season (December 2001) (Figure 4.27). The water temperature related to the air temperature in the same period (Figure 4.1). Then water temperature in all three substations did not differ throughout the year. In addition, the water temperature was slightly different within the seasons. However, the water temperature in subsystem II was higher than in subsystem I and the value reed to its air temperature.

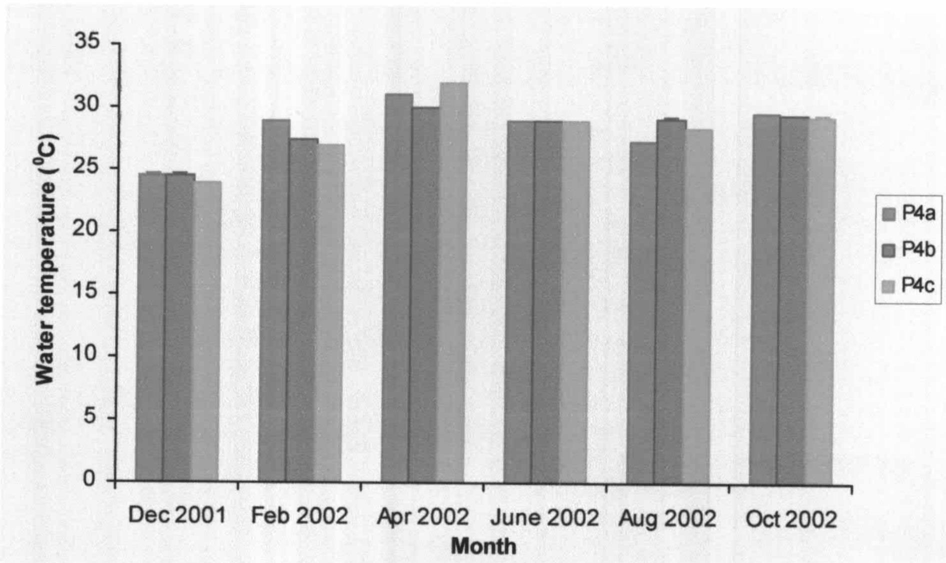


Figure 4.27 Average of water temperature in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream

4.4.1.4 Suspended Solid

The averages of suspended solid (SS) varied from 0.20 to 12.70 mg/l. The highest average of suspended solid was 12.70 mg/l at substation P4a at the beginning of the dry season (December 2001) and the lowest average of suspended solid was 0.20 at substation P4a and P4b at the end of the dry season (April 2002) (Figure 4.28; Table 4 in Appendix D).

Suspended solid had tended to correlate to volume of water and waterflow rate. The water was highly turbid and it might have decreased the amount of oxygen. Then the nitrite-nitrogen could not change into nitrate-nitrogen. Furthermore, the rainfall washed down the soil at the open land and the areas surrounding the reservoir into the water (Wetzel, 2001 and Chen *et al.*, 2003). On the other hand, suspended solid decreased in the middle and at end of the dry season which related to a low waterflow from upstream. The average suspended solids were clearly related to the seasons but did not differ significantly. On the other hand, the suspended solid in April 2002 was significantly different from other periods at the $p = 0.05$ (Table 4.2 in Appendix E)

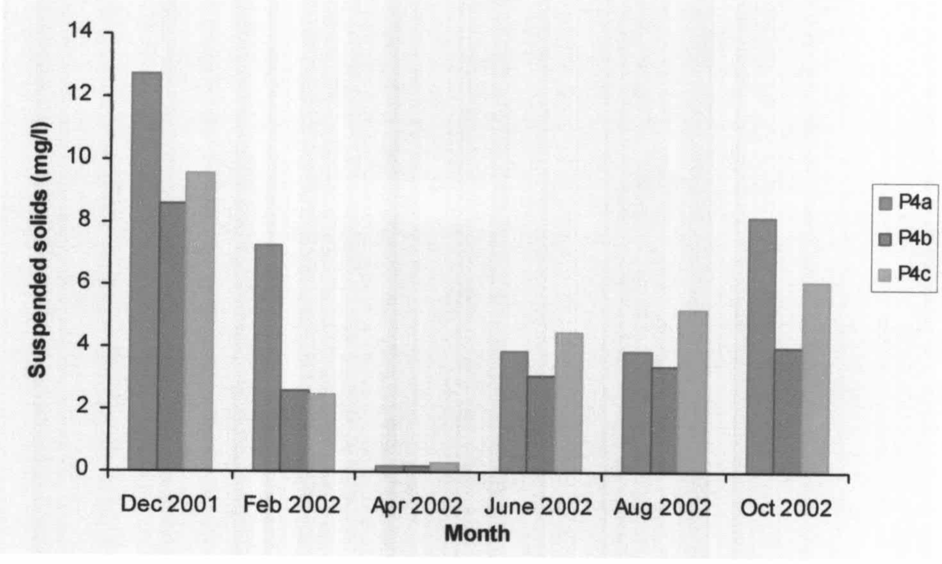


Figure 4.28 Average of suspended solid in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream

4.4.2 Chemical Parameters

The chemical parameters were measured at three substations in Kaeng Krachan Reservoir. They contained the following:

4.4.2.1. pH

The averages of pH of the water varied from 7.30± 0.00 to 8.40 ± 0.00. The highest pH level was 8.40 ± 0.00 at substation P4c in the middle of the wet season (August

2002) and the lowest average pH was 7.30 ± 0.00 at all substations at the beginning of the wet season (June 2002) (Figure 4.29).

The pH of water had tended to increase at substation P4b and P4c at the end of the dry season and remained high throughout in the wet season. It might have been caused by an increase of phytoplankton biovolume. When the phytoplankton blooms, the pH of water may be higher than the normal condition. In this investigation, the pH of water had a positive correlation to phytoplankton biovolume and chlorophyll *a* concentration (Table 17 in Appendix E). The high pH values occur due to intense photosynthetic activity of phytoplankton. This study found the pH value was significantly different within the seasons at the $p = 0.05$ (Table 4 in Appendix E).

Gajaseni (1996) reported that the optimum pH values that are suitable for living organisms in water range from 6.00 to 8.00. This study found that pH values in the wet season were higher than optimum pH values. However, these values were in the ranges of the natural water that are between 6.0 and 8.5 (Chapman, 1992).

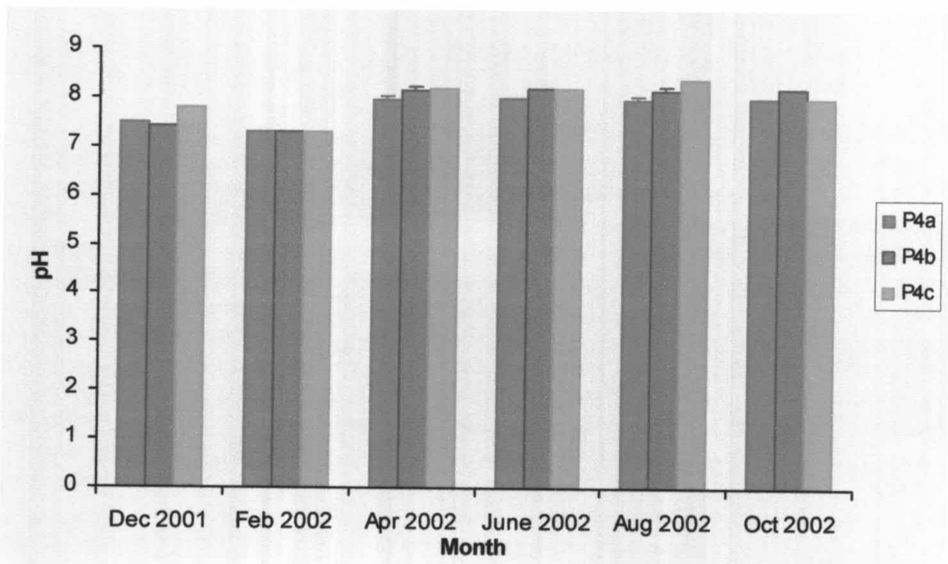


Figure 4.29 Average of pH in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream

4.4.2.2. Dissolved Oxygen

The averages of dissolved oxygen varied from 4.80 ± 0.00 to 7.95 ± 0.07 mg/l. The highest average of dissolved oxygen was 7.95 ± 0.07 mg/l at substation P4c in the middle of the wet season (August 2002) and the lowest average of dissolved oxygen was 4.80 ± 0.00 mg/l at the substation P4b at the beginning of the dry season (December 2001) (Figure 4.30).

The average of dissolved oxygen was related to season. The values fluctuated between high and low levels. In December, dissolved oxygen slightly decreased because of high suspended solid. Dissolved oxygen at substation P4b was lower than other substations significantly different at the $p = 0.05$. This substation is located at a community zone with many restaurants, so of course that waste water washed down into the reservoir (from the interviews). Arobic microbial organism can digest organic matters. In the other hand at substation P4b had small waves lower than at substation P4a and P4c because of lower wind. However, dissolved oxygen was increased slightly in the wet season because phytoplankton bloom. When phytoplankton increases their photosynthesis, the dissolved oxygen also increases.

The study found that most dissolved oxygen in the area of the reservoir was higher than 5 mg/l, that is the optimum of dissolved oxygen value for living organisms in water (Gajaseni, 1996), except at substation P4b in December 2002. Furthermore, the dissolved oxygen in the dry season at this substation was lower than the point figure of the second class surface water quality, which is 6 mg/l (Pollution Control Department, 2001). Thus, there must be concern with regard to the water quality of Kaeng Krachan Reservoir.

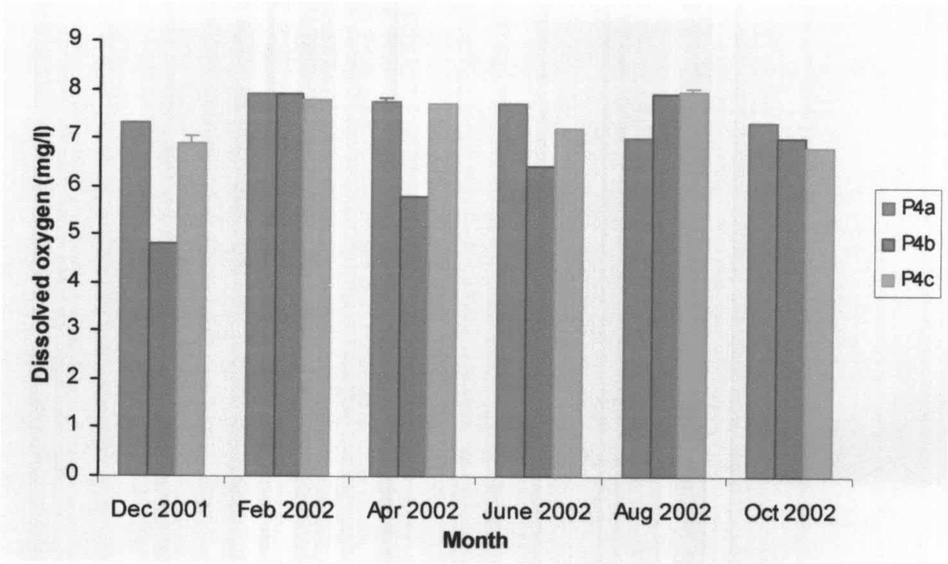


Figure 4.30 Average of dissolved oxygen in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream

4.4.2.3. Nitrate-Nitrogen

The averages of nitrate-nitrogen concentration varied from ND to 25.50 ± 0.66 ug/l. The highest average of this value was 25.50 ± 0.66 ug/l at substation P4c at the beginning of the dry season (December 2002). The values could not be detected at substation P4a and P4b in the middle of the dry season (February 2002) (Figure 4.31).

The average of nitrate-nitrogen concentration was correlated to the water level and rainfall. The average of nitrate-nitrogen concentration was different significantly within the seasons at the $p = 0.05$. In addition, nitrate-nitrogen concentration had a positive correlation to chlorophyll *a* concentration at the $p = 0.01$ (Table 17 in Appendix E). In the wet season, the waterflow washed down the nutrients from the surrounding agricultural land (Fisher *et al.*, 2001). In addition, high erosion in upstream areas increased nutrients and inorganic matters into the reservoir (Wetzel, 2001; Horne, 1994).

This study found that nitrate-nitrogen concentration could detect in low value, it could explain that there were high biovolume of phytoplankton, especially in the wet season (Figure 4.38) and also high chlorophyll *a* concentration (Figure 4.39). It meant that there was high rate of phytoplankton photosynthesis. This could decrease nitrate-nitrogen concentration in the water and it was accumulated in organic forms. (Graham and Wilcox, 2000)

However, the average of nitrate–nitrogen concentration in the reservoir did not exceed 5 mg/l, the maximum figure set as the standard of surface water quality in Thailand (Pollution Control Department, 1997).

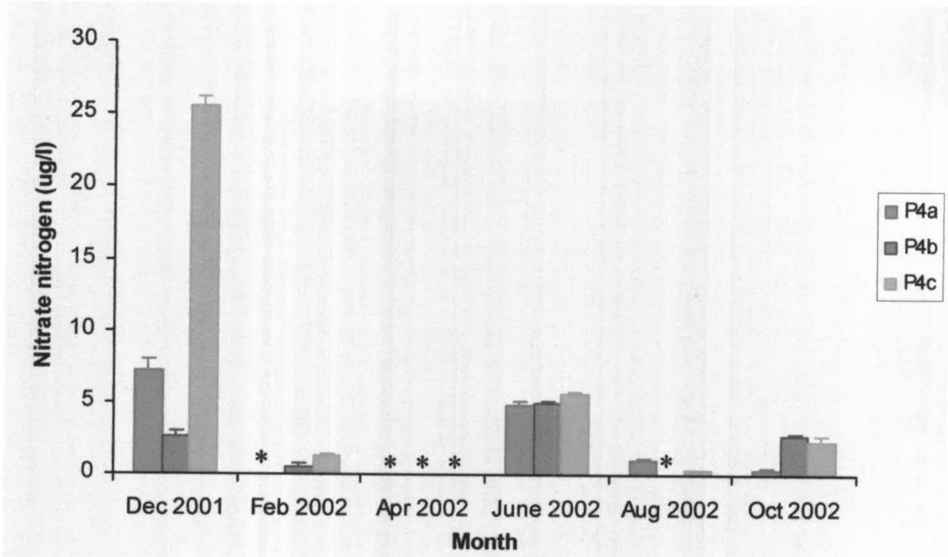


Figure 4.31 Average nitrate-nitrogen in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream, * = could not be detected

4.4.2.4. Nitrite-Nitrogen

The averages of nitrite-nitrogen concentration ranged from 0.23 ± 0.00 to 2.20 ± 0.10 ug/l. The highest average of the value was 2.20 ± 0.10 ug/l at substation P4a at the beginning of the dry season (December 2001) and the lowest value was 0.23 ± 0.00 ug/l at substation P4c at the beginning of the wet season (June 2002) (Figure 4.32).The nitrite-nitrogen concentrations were low throughout the investigation and the values had a positive correlation with suspended solid significantly at p = 0.01 (Table 17 in Appendix E).

The averages of nitrite-nitrogen concentration decreased in the wet season. However, nitrite-nitrogen was low throughout the year. This corresponds to the study of

Sirikhae (2002), who studied nitrite-nitrogen concentration in Rama IX lake, Pathumthanee Province. The study found that nitrite-nitrogen concentration was very low throughout the year, in range of 0.00 – 6.00 ug/l.

The average of nitrite-nitrogen concentration was different significantly within the seasons at $p = 0.05$ (Table 4.2 in Appendix E). Nitrogen concentration had a positive correlation to suspended solid at the $p = 0.01$ (Table 17 in Appendix E). Nitrite-nitrogen is one type of suspended solid. Then when the suspended solid were high, nitrite-nitrogen was also high (De Casabiance, Laugier and Collart, 1997).

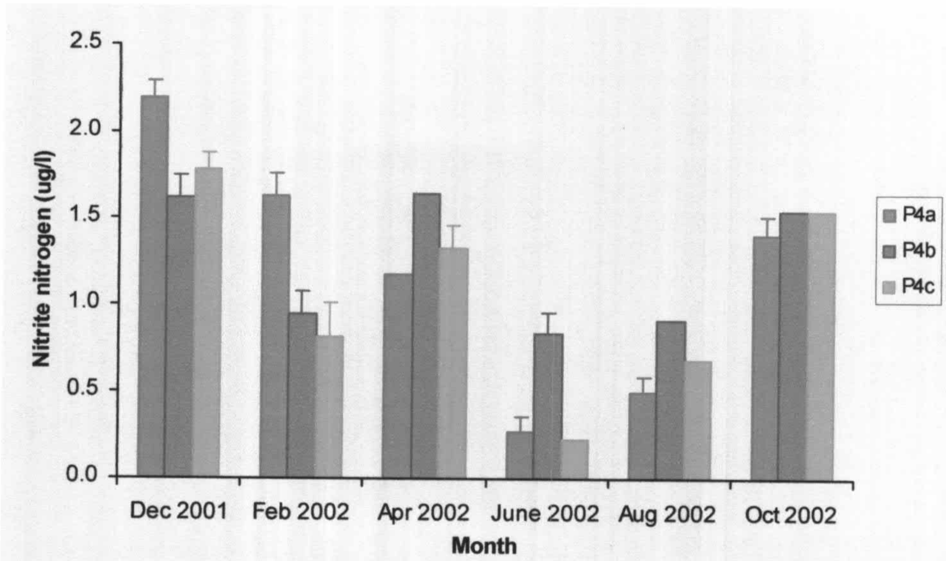


Figure 4.32 Average of nitrite-nitrogen in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream

4.4.2.5. Ammonium-Nitrogen

The averages of ammonium-nitrogen concentration varied from ND to 18.78 ± 0.67 ug/l. The highest average of ammonium-nitrogen concentration was 18.78 ± 0.67 ug/l at the substation P4c in the middle of the wet season (August 2002) and the ammonium-nitrogen concentration could not be detected at all three stations in the middle of the dry season (February 2002) and at the beginning of the wet season (June 2002). It also could not be detected at substation P4a in April 2002 (Figure 4.33).

The average ammonium-nitrogen concentration in December, 2001 and August, 2002 of all stations were higher than other periods because of the rainfall. Then the increasing of ammonium-nitrogen concentration should be affected by the washing from agricultural areas surrounding the reservoir and from the discharge of the upstream. However, the average of ammonium-nitrogen concentration was low throughout the year and did not exceed the standard surface water quality of Thailand which must not exceed 500 ug/l (Pollution Control Department, 1997). In addition, ammonium-nitrogen in most lakes is generally well below at 100 ug/l (Goldman and Horn, 1994). The average of ammonium-nitrogen concentration was not different within the seasons. However, the increasing of ammonium-nitrogen concentration had been clearly related to the discharge and rainfall in year 2001 - 2002 (Figure 4.6).

Phytoplankton can use nitrogen in the ammonium form for their photosynthesis. This study found that there was low nitrate-nitrogen concentration, so it might be that cyanobacteria used the ammonium form. However, the data must be collected long term in the future and there should be concern with regard to ammonium-nitrogen concentration and their sources. High ammonium-nitrogen concentration can affect to aquatic life.

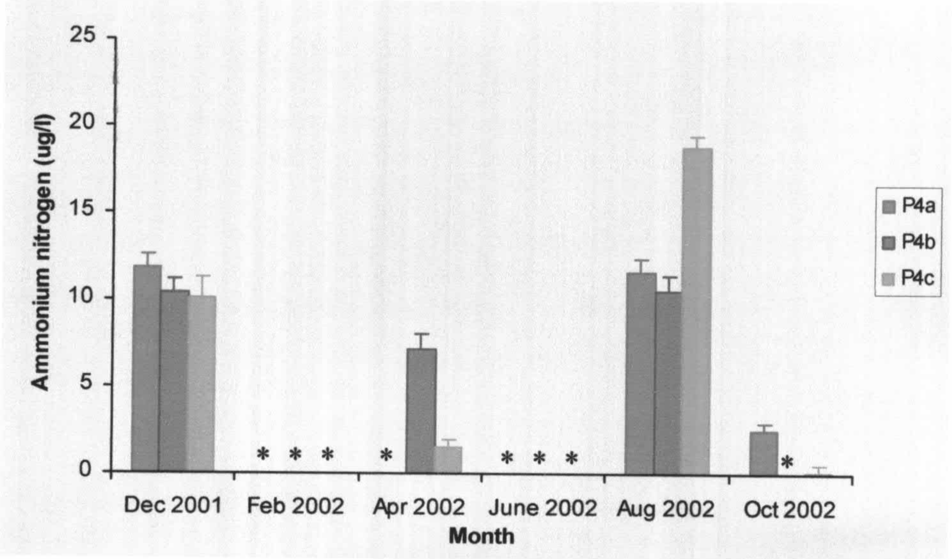


Figure 4.33 Average of ammonium-nitrogen in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream,

* = could not be detected

4.4.2.6. Phosphate-Phosphorus

The averages of phosphate-phosphorus concentration ranged from ND to 7.46 ± 0.00 ug/l. The highest concentration was 7.46 ± 0.00 ug/l at substation P4b and P4c in the middle of the wet season (August 2002) and phosphate-phosphorus concentration could not be detected at all of three stations at the end of the dry season (April 2002) and also could not be detected at substation P4b in the middle of the dry season (February 2002) (Figure 4.34).

The average of Phosphate-phosphorus was significantly different within the seasons at $p = 0.05$ (Table 4.1 in Appendix E). Phosphate-phosphorus was high in the middle of the wet season (August, 2001). It might be affected by nutrients that washed down from the agricultural areas surrounding the reservoir. Phosphorus is essential for all living organisms and is a common growth limiting factor for phytoplankton in lake and reservoir because it is often present in low concentrations. Phytoplankton can uptake only soluble phosphate form (Horne and Goldman, 1994). Watson, McCauley and Downing (1997) reported that in mesotrophic lakes at range 10 - 30 ug TP (Total phosphorus ug/l) the diatoms, cryptophytes and green algae were found. On the other hand, in highly eutrophic regions (≥ 60 ug TP/l), the blue green biomass exhibits the most rapid increase in the waterbody. Furthermore, phytoplankton can store excess phosphorus in polyphosphate granules. When there is a high rate of Phosphate-phosphorus concentration, then phytoplankton can divide several times external Phosphate-phosphorus are depleted (Horne and Goldman, 1994). Based on this study it was found that the biovolume of blue green algae increased rapidly, especially in the wet season (Figure 4.38). The blooms in the wet season indicated that the reservoir must be high Phosphate-phosphorus concentration. Thus, although it could be detected in low concentration, it must be concern with regard to the fertilize uses in agricultural areas surrounding the Kaeng Krachan Reservoir.

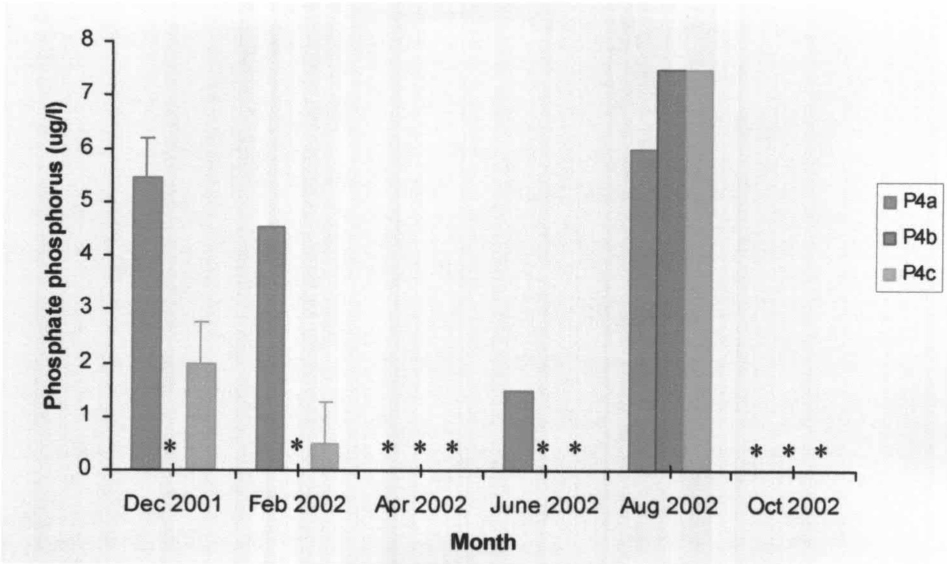


Figure 4.34 Average of phosphate-phosphorus in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream, * = could not be detected

4.4.2.7. Silica-Silicon

The averages of silica-silicon concentration ranged from 2.24 ± 0.00 to 13.14 ± 0.33 mg/l. The highest average of this value was 13.14 ± 0.33 mg/l at substation P4b in the middle of the dry season (February 2002) and the lowest value was 2.24 ± 0.00 mg/l at substation P4a at the end of the dry season (April 2002) (Figure 4.35).

The average of silica-silicon concentration was significantly different within the seasons at $p = 0.05$ (Table 4.1 in Appendix E). The silica-silicon concentration of drainage to natural waters is less variable than many of other major inorganic constituentents (Wetzel, 2001). However, the upstream of Phetchaburi Watershed is a high slope catchment area (Royal Thai Surveys Department, 1991). All nutrients included silica became sediment in the reservoir. In the wet seasons, the high rate of soil erosion can increase silica-silicon concentration into the water. On the other hand, silica – silicon concentration was decreased in the dry season because of the using of aquatic life.

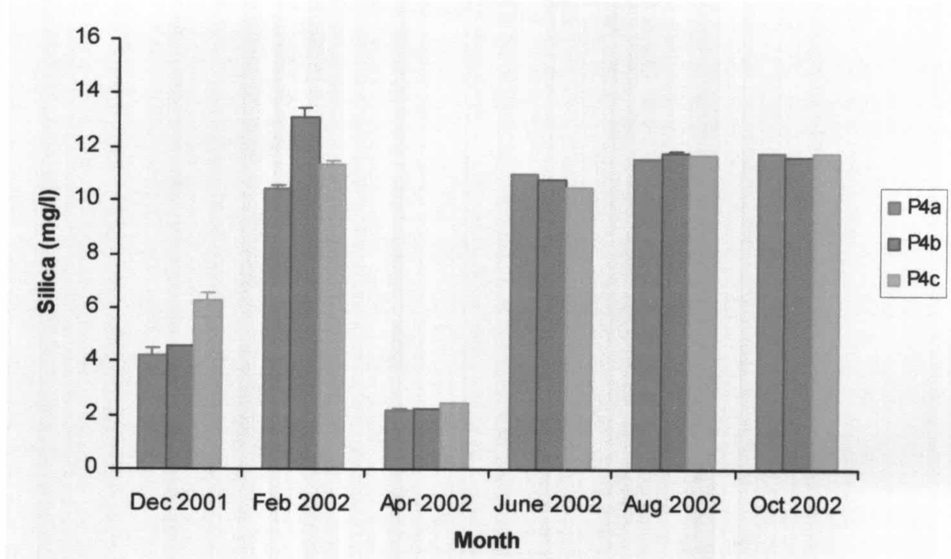


Figure 4.35 Average of silica-silicon concentration in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream

4.4.3 Biological Parameters

For biological parameter, phytoplankton is very important to aquatic ecosystems as a major producer of lentic systems. Therefore; phytoplankton dynamics are examined in order to analyze the relationship to ecological parameters due to seasonal variation as well as land use activities. Thus, the species composition, phytoplankton biovolume and chlorophyll *a* concentration were indicated as follows:

4.4.3.1 Species Composition

A study of biodiversity of phytoplankton was conducted in order to analyze the existing ecological condition of the subsystem II (Kaeng Krachan Reservoir). From December 2001 to October 2002 phytoplankton were found and was classified into 5 divisions, 6 classes 13orders, 24 families, 39 genera and 51 species. In addition, the numbers of phytoplankton in the dry season (44 species) were higher than the in the wet season (35 species). This study found that phytoplankton diversity was higher than the previous study. According to Department of Fisheries (1988) reported that phytoplankton diversity in Kaeng Krachan Reservoir was only 22 species. This might be affected from the increasing of the community and the agricultural areas surrounding the reservoir. The increasing of the land uses can affect the increasing of nutrients of surface runoff into the reservoir. Following Rott's 1981 classifications, this investigation found that the phytoplankton consisted of 7 groups in subsystem II. The Chlorophyceae was the most abundant species with 16 species. There were 13 species of Cyanophyceae and 2 species of Dinophyceae. Ten species of Diatomophyceae were found. The Zygnemaphyceae were 6 species, Crytophyceae were 3 species, and only one species of Chrysophyceae was found (Table 4.5). However, the majority groups of phytoplankton were Cyanophyceae, Dinophyceae, Chlorophyceae and Zygnemaphyceae, respectively.

Comparison can be made to the phytoplankton diversity studies in northern reservoir of Thailand. As the result of this study was the same as Peerapornpisal (1996) who reported that Chlorophyceae was the most species richness group and Cyanophyceae was the majority groups of phytoplankton in the three reservoirs in the Huai Hong Khrai Royal Development Study Centre, Chiang Mai.

Table 4.5 List of species of phytoplankton survey in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Phytoplankton species	
Cyanophyceae	*Anabaena* sp.1
	Anabaena sp.2
	Anabaena sp.3
	Aphanocapsa sp.
	Coelomoron sp.
	Cylindrospermopsis sp.
	Lyngbya sp.
	Merismopedia sp.
	Microcystis aeruginosa
	Oscillatoria sp.
	Planktolyngbya sp.
	Pseudanabaena sp.
	Spirulina sp.
Cryptophyceae	*Chroomonas sp.*
	Cryptomonas sp.
	Rhodomonas sp.
Dinophyceae	*Ceratium sp.*
	Peridinium sp.
Diatomophyceae	*Cyclotella sp.*
	Fragilaria sp.2
	Gyrosigma sp.
	Meloseira sp.
	Navicula sp.1
	Navicula sp.2
	Nitzschia sp.1
	Nitzschia sp.2
	Surirella sp.
	Tabellaria sp.
Chrysophyceae	*Dinobryon sp.*
Chlorophyceae	*Ankistrodesmus* sp.
	Botryococcus braunii
	Coelastrum sp.
	Crucigenia sp.
	Dictyosphaerium sp.
	Eudorina sp.
	Pediastrum sp.1
	Pediastrum sp.2
	Planktonema sp.
	Scenedesmus sp.1
	Scenedesmus sp.2
	Scenedesmus sp.3
	Scenedesmus sp.4
	Spirogyra sp.1
	Tetraedron sp.
	Ulothrix sp.
Zygnemaphyceae	*Cosmarium* sp.1
	Cosmarium sp.3
	Cosmarium sp.4
	Staurastrum sp.1
	Staurastrum sp.2
	Staurastrum sp.3

4.4.3.2 Dominant Species

Subsystem II (Kaeng Krachan Reservoir) of the Phetchaburi Watershed had 3 substations. The dominant species in Kaeng Krachan Reservoir were composed of Cyanophyceae (*Microcystis aeruginosa, Oscillatoria* sp. and *Cylindrospermopsis raciborskii*), one species of Dinophyceae that was *Peridinium* sp., one species of Zygnemaphyceae that was *Staurastrum octoverrucosum* var. *simplicius* and one species of Chlorophyceae that was *Botryococcus braunii*, respectively. *Peridinium* sp. was the dominant species in the dry season (December 2001 to February 2002) and *M. aeruginosa* was the dominant species in the late of the dry season and throughout the wet season. The dominant phytoplankton species were shown in Figure 4.36.

Comparison can be made to the study of Panuvanitchakorn (2003) who reported that toxic cyanobacteria *Microcystis* spp. were investigated in Lamtakong Reservoir, Nakorn Ratchasima Province. However, *Fragilaria ulna* was the dominant species in the reservoir. While Peerapornpisal (1996) reported that the cyanobacteria, *C. raciborskii* was the dominant species in the three reservoirs in the Haui Hong Khrai Royal Development Study Centre, Chiang Mai.

The numbers of phytoplankton species were slightly different within the seasons (Figure 4.37). The numbers of species in each month at substation P4a was different from at substation P4b and P4c. It could be explained that substation P4a located at the water inlet of the reservoir (the riverine zone). The water was high turbid because of streamflow from the upstream. In addition, its velocity might be like a lotic ecosystem. These reasons could have the effect of reducing the phytoplankton growth including chlorophyll *a* concentration (Sommer, 1989; Wetzel, 2001). On the other hand, substation P4b and P4c were clean and low influence of streamflow, so it was suitable for phytoplankton growth. However, the number of phytoplankton species had tended to reduce in the wet season. This might have the effect of causing phytoplankton to bloom (Wetzel, 2001). When phytoplankton were bloom, their numbers of species usually decrease and they were also reduced the diversity. This study found that when phytoplankton in the reservoir were bloom, the numbers of phytoplankton species also decreased.

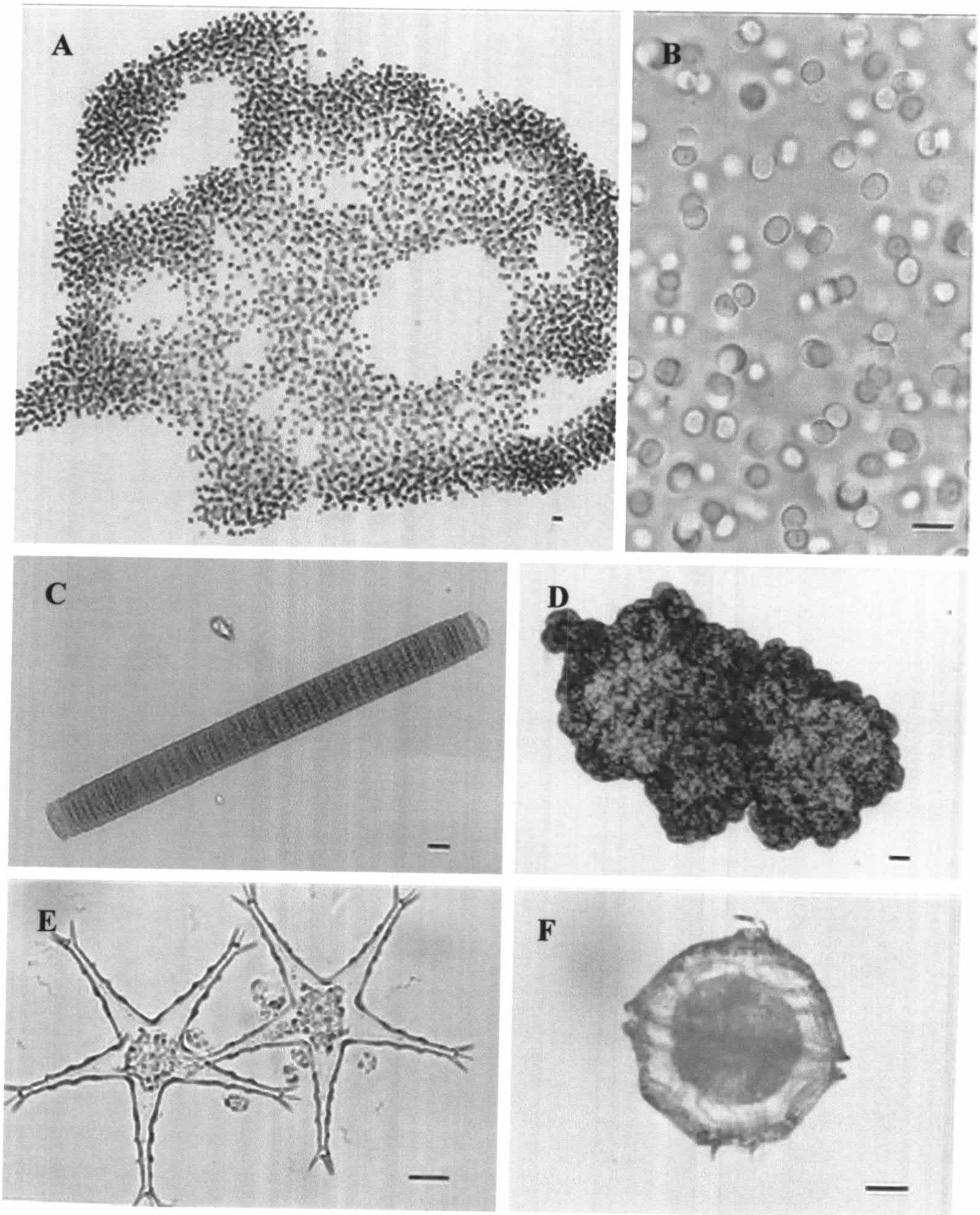


Figure 4.36 Dominant phytoplankton species in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed, *Microcystis aeruginosa* (A and B), *Oscillatoria* sp. (C), *Botryococcus braunii* (D), *Staurastrum* sp. (E) and *Peridinium* sp. (F), scale bar — = 10 micron

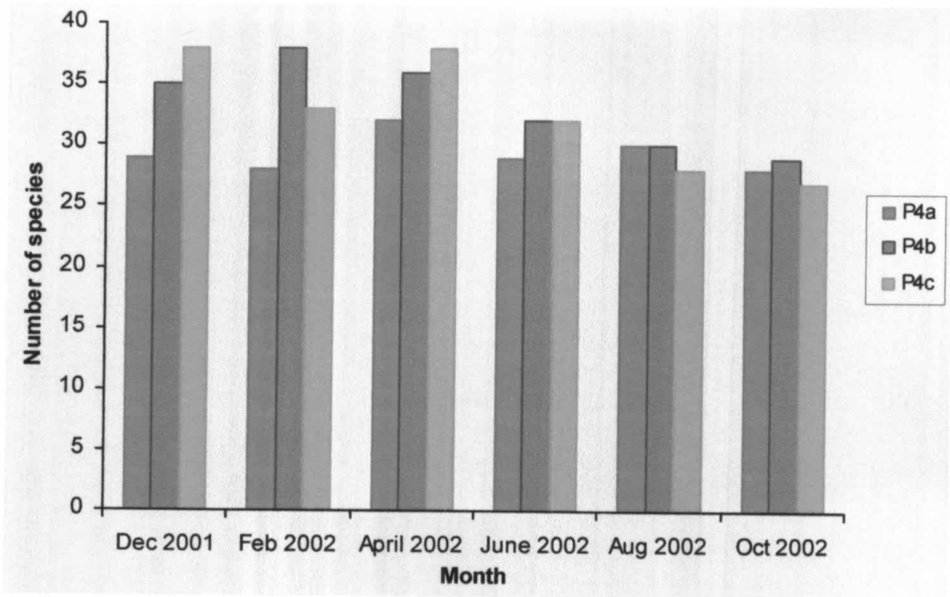


Figure 4.37 Number of species composition of subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream

4.4.3.3 Phytoplankton Biovolume in Subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

The biovolume of phytoplankton was calculated from the abundance and volume approximation of each species (Table 4.6). The values had tended to correlate within the seasons. The average of phytoplankton biovolume ranged from $2.76 \times 10^3 \pm 0.10 \times 10^3$ to $2.20 \times 10^4 \pm 0.11 \times 10^4$ mm^3/m^3 (Table 4.7). The highest value was $2.20 \times 10^4 \pm 0.11 \times 10^4$ mm^3/m^3 in the late part of the wet season (October 2002) and the lowest value was $2.76 \times 10^3 \pm 0.10 \times 10^3$ mm^3/m^3 at the beginning of the dry season (December 2001). Phytoplankton biovolume was significantly different within the seasons at the $p = 0.05$. The annual average of phytoplankton biovolume in Kaeng Krachan Reservoir was 5,424 mm^3/m^3.

The phytoplankton biovolume was low in the dry season and increased rapidly at the beginning of the wet season due to rainfall (Figure 4.38). Figure 4.38D showed *Peridinium* sp. was the highest biovolume at 42.73 % in the dry season (February 2002). Then, *M. aeruginosa* were highly biovolume in the late of the dry season (April 2002) and rapidly grew up to have the biggest biovolume at 78.01% in October

Table 4.6 Biovolume of phytoplankton species in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Phytoplankton species	Volume			Volume (um^3)	Geometric shape	Shape
	Cell	Filament	Colony			
Cyanophyceae						
Anabaena sp.1		✓		4,720	Cylinder	Filament
Anabaena sp.2		✓		1,248	Cylinder	Filament
Anabaena sp.3		✓		722	Cylinder	Filament
Aphanocapsa sp.			✓	82	Sphere	Colony
Coelomoron sp.			✓	178	Ellipsoid	Colony
Cylindrospermopsis sp.		✓		330	Cylinder	Filament
Lyngbya sp.		✓		10,200	Cylinder	Filament
Merismopedia sp.			✓	130	Sphere	Colony
Microcystis aeruginosa	✓			54	Sphere	Colony
Oscillatoria sp.		✓		12,120	Cylinder	Filament
Planktolyngbya sp.		✓		48	Cylinder	Filament
Pseudanabaena sp.		✓		240	Cylinder	Filament
Spirulina sp.		✓		1,372	Cylinder	Filament
Crytophyceae						
Chromonas sp.	✓			580	Elliptic-ellipsoid	Cell
Cryptomonas sp.	✓			418	Elliptic-ellipsoid	Cell
Rhodomonas sp.	✓			92	Elliptic-ellipsoid	Cell
Dinophyceae						
Ceratium sp.	✓			34,140	3 cones	Cell

Table 4.6 (Cont.) Biovolume of phytoplankton species in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Phytoplankton species	Volume			Volume (um^3)	Geometric shape	Shape
	Cell	Filament	Colony			
Dinophyceae (Cont.)						
Peridinium sp.	✓			4,226	Ellipsoid-ellipsoid	Cell
Diatomophyceae						
Cyclotella sp.	✓			3,416	Sphere	Cell
Fragilaria sp.2	✓			612	Parallelepiped	Cell
Gyrosigma sp.	✓			7,724	Parallelepiped	Cell
Meloseira sp.	✓			204	Cylinder	Cell
Navicula sp.1	✓			710	Parallelepiped	Cell
Navicula sp.2	✓			236	Parallelepiped	Cell
Nitzschia sp.1	✓			404	2 Trapezoids	Cell
Nitzschia sp.2	✓			218	2 Trapezoids	Cell
Surirella sp.	✓			4,860	Cone-elliptic	Cell
Tabellaria sp.	✓			3,000	Parallelepiped	Cell
Chrysophyceae						
Dinobryon sp.	✓			264	Cone	Cell
Chlorophyceae						
Ankistrodesmus sp.			✓	342	2 cones	Colony (8 cell)
Botryococcus braunii			✓	12,660	2 Ellipsoid	Colony (8 cell)
Coelastrum sp.			✓	1,488	Sphere	Colony (8 cell)
Crucigeniella sp.			✓	76	4 Triangular-parallelepipe	Colony (4 cell)

Table 4.6 (Cont.) Biovolume of phytoplankton species in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Phytoplankton species	Volume			Volume (um^3)	Geometric shape	Shape
	Cell	Filament	Colony			
Chlorophyceae (Cont.)						
Dictyosphaerium sp.			✓	244	Sphere	Colony
Eudorina sp.			✓	6,420	Ellipsoid	Colony (32 cell)
Pediastrum sp.1			✓	2,426	Trapezoid+2Triangular	Colony
Pediastrum sp.2			✓	1,350	Trapezoid+2Triangular	Colony
Planktonema sp.		✓		848	Cylinder	Filament
Scenedesmus sp.1			✓	286	Ellipsoid	Colony (2 cell)
Scenedesmus sp.2			✓	224	Ellipsoid	Colony
Scenedesmus sp.3			✓	472	2 cones	Colony (4 cell)
Scenedesmus sp.4			✓	84	Ellipsoid	Colony
Spirogyra sp.1		✓		122,840	Cylinder	Filament
Tetraedron sp.	✓			106	Parallelepipe	cell
Ulothix sp.	✓			210	Cylinder	Filament
Zygnemaphyceae						
Cosmarium sp.1	✓			1,644	2 Elliptic-Ellipsoid	Cell
Cosmarium sp.3	✓			266	2 Elliptic-Ellipsoid	Cell
Cosmarium sp.4	✓			154	2 Elliptic-Ellipsoid	Cell
Staurastrum sp.1	✓			3,326	Parallelepiped+4Truncated	Cell
Staurastrum sp.2	✓			1,590	Parallelepiped+4Truncated	Cell
Staurastrum sp.3	✓			478	Parallelepiped+4Truncated	Cell

2002. In addition, other blue-green algaes, *Oscillatoria* sp. and *C. raciborskii* also highly increase their biovolume. Although *B. braunii* noticeably bloomed, its colony floated at the water surface and possibly missed from water sampler collection.

From the study, *Peridinium* sp. was the highest biovolume in the dry season. The Dinophyceae such as *Peridinium* and *Ceratium* spp. usually present in medium nutrients rich or mesotrophic lakes (Wetzel, 2001). While three species of Cyanophyceae as *M. aeruginosa*, *C. raciborskii* and *Oscillatoria* sp. were dominant throughout the year, especially *M. aeruginosa* bloomed and were the highest biovolume in the wet season. The study was the same as Peerapornpisal *et al.* (1999) who reported that *M. aeruginosa* grew rapidly and bloomed in Mae Kuang Udomtara reservoir, Chiang Mai Province. In eutrophic lakes, Cyanophyceae can bloom and divided cells rapidly because of enriched nutrients (Wetzel, 2001). Furthermore, lake and reservoir ecosystems are suitable condition for *M. aeruginosa* growth (Wetzel, 2001); (Chen, et al., 2003). This study also found that, when *M. aeruginosa* highly increased their biovolume in the wet season, the number of cells per colony also increased. Wetzel (1983) reported that during the bluegreen algae bloom, the population growth of the algae could be strongly suppressed because the bluegreen algae are able to release hydroxamate siderchrome compounds with complex ions favoring the growth of bluegreen algae. The hydroxamate chelators exerted growth suppressing effects on non bluegreen algae.

In recent year the toxic phytoplankton, *C. raciborskii*, has replaced bloom-forming Cyanophyceae (Chapman and Schelske, 1997). This study also found that *C. raciborskii* were dominant species and their biovolume increased rapidly in the wet season. *C. raciborskii* has aerotopes that affect the floating and sinking of its. It can remain near the optimum light level and also shade out the competing algae (Goldman and Horne, 1983). In addition, this species is able to fix nitrogen from the environment and convert it to ammonium and protein (Harris, 1986; Peerapornpisal, 1996). Then this also protects it from the occasional depletion of this nutrient.

Furthermore, there were some studies in Northern Thailand reservoirs which found that *C. raciborskii* were dominant species and were the highest biovolume in three reservoirs in the Huai Hong Khrai Royal Development Study Centre, Chiang Mai

Province (Peerapornpisal, 1996). In addition, Pongswat (2002) reported that. *C. raciborskii*, were the highest biovolume in two reservoirs of Rama IX Lake, Pathumthani Province.

Table 4.7 Phytoplankton biovolume in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Month	Substation	Phytoplankton biovolume (mm^3/m^3)
Dec-01	P4a	2775.83 ± 86.82
	P4b	2789.10 ± 77.87
	P4c	2712.02 ± 71.17
Feb-02	P4a	5603.06 ± 226.16
	P4b	3878.04 ± 130.31
	P4c	3444.84 ± 117.9
Apr-02	P4a	3775.63 ± 134.73
	P4b	6668.16 ± 248.28
	P4c	4649.23 ± 147.32
Jun-02	P4a	6509.79 ± 351.96
	P4b	8765.38 ± 585.37
	P4c	6687.23 ± 406.02
Aug-02	P4a	7446.55 ± 422.48
	P4b	5802.36 ± 315.13
	P4c	7082.63 ± 320.65
Oct-02	P4a	28305.13 ± 1941.89
	P4b	17855.09 ± 1185.79
	P4c	20875.17 ± 1308.77

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream

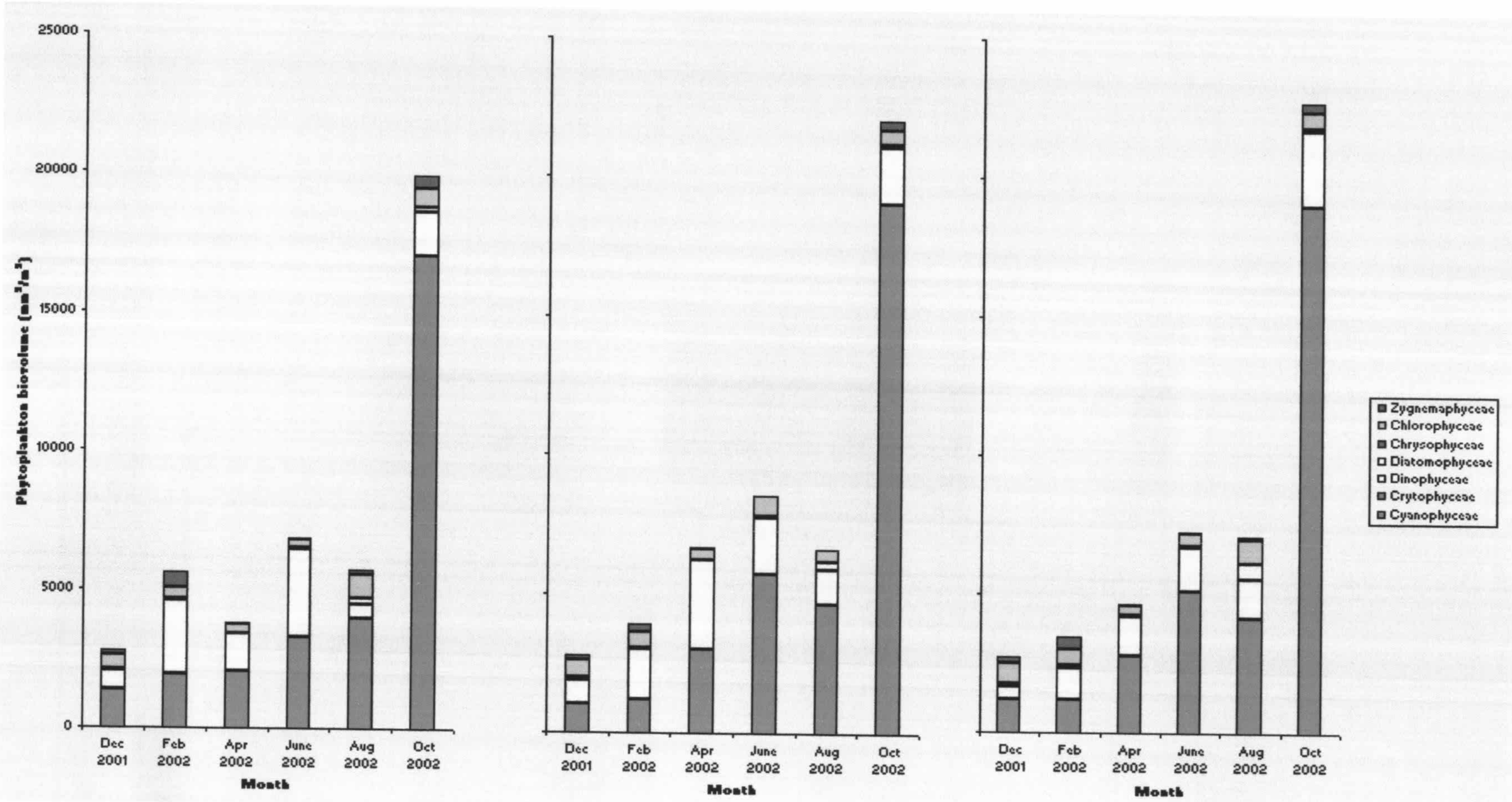


Figure 4.38 Seasonal variation of phytoplankton biovolume (mm^3/m^3) and portion of the taxonomic groups in station P4a (A), station P4b (B) station P4c (C) and total biovolume of dominant species using 10% of the total species of phytoplankton (D)

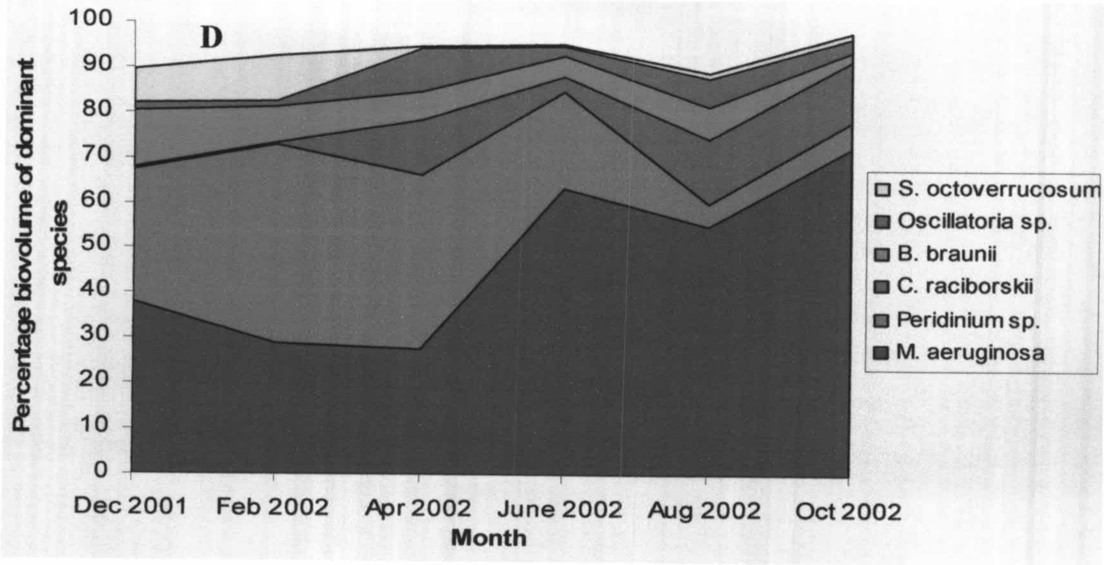


Figure 4.38 (Cont.) Seasonal variation of phytoplankton biovolume (mm^3/m^3) and portion of the taxonomic groups in station P4a (A), station P4b (B) station P4c (C) and total biovolume of dominant species in Kaeng Krachan Reservoir using 10% of the total species of phytoplankton (D)

4.4.3.4 Chlorophyll *a*

The averages of chlorophyll *a* concentration ranged from 9.62 ± 0.27 to 41.53 ± 0.87 mg/m^3. The highest average of chlorophyll *a* concentration was 41.53 ± 0.87 mg/m^3 at substation P4c at the end of the wet season (October 2002) and the lowest was 9.62 ± 0.27 mg/m^3 at the substation P4b in the middle of the dry season (February 2002) (Figure 4.39). At the beginning of the wet season, there were phytoplankton blooms and both chlorophyll *a* concentration and phytoplankton biovolume were increased rapidly until October, 2002. The amount of chlorophyll *a* in the middle of transparency depth was higher both at the surface and at 5 metres depth. Chlorophyll *a* is a major pigment in every kind of phytoplankton cell and it is important in the photosynthesis. This study found that chlorophyll *a* concentration had a positive correlation with phytoplankton biovolume significantly at the $p = 0.001$ (Table 17; Appendix E).

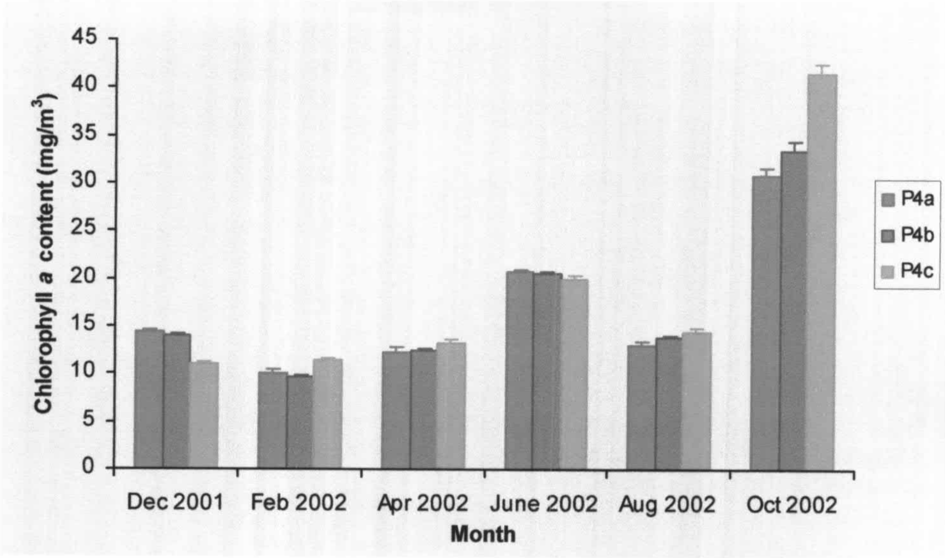


Figure 4.39 Average of chlorophyll *a* in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream

The values of phytoplankton biovolume and chlorophyll *a* concentration were significantly different within the seasons at the $p = 0.05$ (Table 4.1 in Appendix E). Dinophyceae was dominant in the dry season and Cyanophyceae was dominant throughout the year, especially in the wet seasons, which meant that water quality is under threat due to nutrient enrichment. This study analyzed chlorophyll *a* concentration following Wetzel and Likens (2000) study. The method used a 0.45 Millipore filter, so the chlorophyll *a* concentration in this study was higher than the studies that used GF/C paper. In recent years, many researches indicated that picophytoplankton (0.2 – 2.0 micron) and nanophytoplankton (2.0 – 20.0 micron) presented as major groups for photosynthesis in aquatic ecosystem (Jasser and Arvola, 2003). Then this study found, although the phytoplankton density (20 – 200 micron) in the dry season was lower than in the wet season in many times, its chlorophyll *a* concentration remained high. However, when plankton bloomed, some phytoplankton species were a bigger colony and might have decreased the efficiency of method of chlorophyll *a* concentration (Peerapornpisal, 1996).

The chlorophyll *a* concentration in Kaeng Krachan Reservoir had tended to correlate with rainfall (Figure 4.5). The discharge in rainy periods increased nutrients in waterbodies. Then this study also found that both chlorophyll *a* and phytoplankton biovolume in the reservoir were very high after rainy periods. The annual year of chlorophyll *a* concentration was 17.22 ± 4.44 mg/m^3, these values were in ranges of mesotrophic eutrophic lake (Wetzel, 2001). Comparison to Peerapornpisal (1996) reported that chlorophyll *a* concentration in the three reservoirs in Northern Thailand were 18, 35 and 25 mg/m^3.

4.4.3.5 Shannon-Wiener's Index of Phytoplankton in subsystem II

Shannon-Wiener's Index of phytoplankton in the reservoir ranged from 0.215 to 1.203 (Table 4.8). The highest value was 1.203 in the middle of the dry season (February 2002). The value of the index had tended to correlate within the seasons. Although they were slightly different in species numbers, the increasing of phytoplankton biovolume in the wet season might affect to decrease the value of Shannon-Wiener's Index.

Table 4.8 Shannon-Wiener's Index of phytoplankton in subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

Shannon-Wiener's Index							
Substation	Dec-01	Feb-02	Apr-02	Jun-02	Aug-02	Oct-02	Annual year
P4a	0.417	0.495	0.676	0.34	0.38	0.259	0.428
P4b	0.652	0.641	0.953	0.283	0.491	0.308	0.555
P4c	0.808	1.203	0.939	0.215	0.371	0.274	0.635
P4	0.626	0.780	0.856	0.279	0.414	0.280	0.598

Note: P4 is Kaeng Krachan Reservoir, P4a = inlet water from upstream, P4b = water in the reservoir, P4c = outlet water from reservoir to downstream

The values of diversity index of all three substations in the dry season were higher than the values in the wet season. The phytoplankton Blooms throuthout the wet season affected to decrease the value of the diversity index. This study found that the highest value of phytoplankton diversity index of Kaeng Krachan Reservoir was 0.856 in April and the annual year value of the index was 0.598. In addition, it found that the annual year value of the diversity index at the outlet of the reservoir (station

P4c) was higher than at the inlet (station P4a) and in the middle of the reservoir (station P4b). The area in front of the dam is suitable for phytoplankton growth such as, it was calm and low influence of streamflow (Wetzel, 2001). On the other hand, the diversity index at the inlet of the reservoir (station P4a) was the lowest value because this area was disturbed by streamflow and it was specific phytoplankton species in this condition.

4.4.4 The Correlation between Ecological Parameters in Subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

According to correlation analysis, phytoplankton biovolume had a positive correlation to chlorophyll *a* concentration significantly at the $p = 0.001$ (Table 17 in Appendix E). In addition, the biovolume of *M. aeruginosa* had a positive correlation to total biovolume and Chlorophyll *a* concentration significant at the $p = 0.001$ and 0.01, respectively. Chlorophyll *a* concentration had a positive correlation to nitrate-nitrogen concentration significantly at the $p = 0.0001$. Although nitrate-nitrogen concentration could be detected in low volume was low throughout the investigation, the total biovolume remained high because of the increasing of cyanophyte biovolume. Cyanophyceae is an important nitrogen-fixing planktonic bloom-former in tropical freshwaters around the world (Graham and Wilcox, 2000).

However, both of phytoplankton biovolume and chlorophyll *a* concentration had a negative correlation to Phosphate-phosphorus concentration significantly at $p = 0.05$ and 0.0001, respectively. It could explain that phytoplankton was bloom throughout the wet season. Phosphorus is essential for all living organisms and is a common growth limiting factor for phytoplankton in lakes and reservoirs because it is often available in low concentrations with high turn-over rate. Phytoplankton can use only soluble phosphate form (Goldman and Horne, 1994), while phytoplankton were blooming the rate of phosphorus uptake was high. Then this study could not be detected soluble phosphate form during the bloom periods, especially in October (2002). Considering that phytoplankton can store excess phosphorus in polyphosphate granules when there was a high value of Phosphate-phosphorus concentration, then phytoplankton can divide several times while external Phosphate-phosphorus are depleted (Goldman and Horne, 1994). Besides, several cyanobacteria of lakes exhibit vertical migrations from phosphorus-rich sediments at night to surface water in early morning (Chapman and Schelske, 1997). Chlorophyll *a* concentration had a negative correlation to suspended solids significantly at the $p = 0.01$. The high value of suspended solids can interfere light penetration through water and effect to photosynthesis of phytoplankton.

From the study in Kaeng Krachan Reservoir, the phytoplankton biovolume and chlorophyll *a* concentration increased in the wet season because the water inflow and rainfall washed the organic matter and nutrients from the land into the reservoir. On the other hand, the forest areas in upstream were given concession and some were converted into agricultural areas especially the surrounding area of the reservoir. It is absolutely effect that fertilizer was washed down into the reservoir. Phytoplankton bloomed throughout the wet season and remained in bloom until February 2003 (the notice after study period).

Table 4.9 showed some ecological characteristics of the lentic ecosystem in tropical region. Some parameters, especially biovolume were difficult to compare because of the different units. However, the taxonomic groups dominating phytoplankton biovolume of eutrophic water bodies in many countries were similar. Cyanophyceae were the dominant group followed by Chlorophyceae, Euglenophyceae and Bacillariophyceae, respectively. *Microcystis* and *Cylindrospermopsis* were dominant species in most areas. Comparison the three reservoirs in the Huai Hong Khaki Royal Development Study Centre, Northern Thailand, the values were 2,963, 7,899 and 4,681 mm^3/m^3, respectively (Peerapornpisal, 1996). While in the two reservoirs of Rama IX Lake, Central Thailand, they were 4,452 and 495 mm^3/m^3, respectively (Pongswat, 2002). However, when comparison the characteristic of water bodies, the lakes had tend to be higher nutrient enrich and eutrophication than the reservoirs.).

A World Health Organization (WHO) in a guideline for drinking water quality identified cyanobacteria as one of the most urgent areas in which guidance was required (Chorus and Bartram, 1999). The WHO guideline for microcystins in finished drinking water is 1 $\mu g/L$ (ppb), based on microcystin-LR, a specific microcystin toxin.

Table 4.9 Comparison of physico-chemical and biological characteristics (annual averages) and dominant groups in lentic ecosystem from mesotrophic to hypereutrophic lakes and reservoirs and in the tropical region (Re = Reservoir, L = lake)

Country or Region	Thailand							Sri Lanka *		Indonesia *	Brazil *	
	Present study		Peerapornpisal, 1996			Pongswat, 2002		Gunatilaka and Rott 1984 (unpublished data)		Rondo, 1990	Bronco and Senna, 1994	
Name of lake or reservoir	Re		Re	Re	Re	Re	Re	L	L	L	L	
	Dry season	Wet season	A	B	C	1st Rama IX	2nd Rama IX	PSN	PSM	Tondano	Dry season	Wet season
Secchi depth (m)	1.6	1.20	0.7	0.7	0.9	0.96	1.86	0.6	1.3	-	7	4.7
Phosphate - Phosphorus	3	1	15	18	12	4	4	4	-	126	7	5
Nitrate-nitrogen (ug/l)	9	3	26	16	22	20	12	4	-	421	173	110
Chlorophyll *a* (ug/l)	12	27	18	35	25	10	3	45	29	-	42	69
Biovolume (mm^3/m^3) (Individuals/l)	2,317	7,024	2,963	7,899	4,681	4,452	495	25,000	-	2,595	42×10^6	62×10^6
Phytoplankton groups or species	Dinoph. : *Peridinium* sp. Cyano. : *M. aeruginosa*	Cyano. : *M. aeruginosa* *C. raciborkil* - Chloro *B. braunii*	Cyano. : *C. raciborkil* *C. phillipinensis* Chloro. : *B. braunii*			Cyano. : *C. raciborkil*		Cyano. : *C. raciborkil*	Bacill. : *Synedra sp.*	Cyano. : Eugleno. :	Cyano. : *M. aeruginosa*	Cyano. : *C. raciborkil*

Note: * = Site in Peerapornpisal, 1996

Microcystis spp. can occur worldwide in eutrophic lakes and drinking water reservoirs (Chen, et al., 2003). In a survey of 167 water samples in Florida, Microcystis (43%), Cylindrospermopsis (40%) and Anabaena (29%) were observed most frequently (Williams et al., 1999). These cyanobacteria also occurred at greatest concentrations in the waters sampled (Williams et al., 1999). With another cyanobacteria outbreak in Brazil that caused mortality in a dialysis unit, *Anabaena* and *Microcystis* genera were present in the water at 1,104 and 9,755 units (units refers to colonies which could be up to 100 cells) per ml (Pouria et al.,1998). In Florida surface waters *Cylindrospermopsis* species counts exceeded 8,000 cells/ml for several sites during the summer months (Williams et al., 1999).

Currently many water utilities are concerned about controlling odor and taste and may not fully appreciate the potential consequences of long-term low concentration exposure. With the diversity of toxins, it would appear prudent to focus first on microcystin, the toxin that occurs most frequently in surface water. Many of the reported adverse human effects from cyanotoxins derive from of epidemiology studies or antidotal reports from poisonings. Not all reports carefully define the organism and especially the toxin since only recently have analytical procedures been available for these complex toxins. In 1931, low rainfall caused the water in a side branch of the Ohio River to develop a cyanobacterial bloom that was then washed into the main river. As the bloom washed down the river, a series of gastroenteritis outbreaks occurred this could not be attributed to infectious disease (Chorus and Bartram, 1999). In Harare, Zimbabwe, gastritis in children drinking water from a reservoir coincides with a *Microcystis* bloom each year and in Brazil 88 deaths were reported to be associated with cyanobacterial toxins (Pouria et al., 1998).

In China, the highest incidence of liver cancer occurs in areas with abundant cyanobacteria in the surface waters (Chorus and Bartram, 1999). The WHO has noted that these cyclic peptides represent the greatest concern to human health because of their potential exposure to low concentrations for long-periods of time. The human incidences of cyanobacteria toxicity and the ecotoxicity have focused almost entirely on the acute episodes. There is a crucial need for chronic drinking water toxicity studies. With diminishing clean water supplies, increasing eutrophication of surface waters and global climate changes, cyanobacteria toxicity are emerging issues. While microcystin LR is a logical first toxin for evaluation, Cylindrospermopsis and Anabaena toxins should also be considered (Williams et al., 1999).

Freshwaters in Thailand have been eutrophicated by industrial, agricultural and municipal wastewater. *M. aeruginosa* were studied in Mae Kuang Udomtara Reservoir, Chiang Mai Province, Thailand and found that, *Microcystis* spp. are toxic phytoplankton (Peerapornpisal, et al., 1999). Microcystins were accumulated in fish livers, viscera and muscle tissue, and aquatic animals (Megalhaes, Soares and Azevedo, 2001). Then they can be extremely dangerous. In addition, Peerapornpisal et al. (2002) surveyed and monitored toxic cyanobacteria in six raw water resources in many parts of Thailand. They found that all six reservoirs were contaminated by *M. aeruginosa*. However, the level of microcystins found in all reservoirs was lower than those determined by the World Health Organization for the raw water uses for water supplies.

This study found that Dinophyceae was dominant in the dry season and Cyanophyceae was dominant throughout the year, especially in the wet season. That means the water quality is under threat of nutrient enrichment. Furthermore, the toxic cyanophyte, *M. aeruginosa* were in bloomed throughout the year. Even the degree of blooming was still low when compared to temperate blooming. Then, it must be a cause for serious concern and increased awareness of the impact of the land use on a system. All land use activities in the reservoir need to be managed sustainably in order to protect the serious health impacts in future.

Based on this study, the water quality in the reservoir classified by standard surface water quality in Thailand was found to be the second to third category and was relatively suitable for fisheries and water supplies when properly treated (Pollution Control Department, 1997). However, by the trophic level Kaeng Krachan Reservoir can be classified as mesotrophic eutrophic lake in the dry season and eutrophic lake in the wet season (Wetzel, 2001).

4.5 Ecological Relationships of Subsystem III

As results, the ecological parameters as physico-chemical parameters were shown in relation to seasonal variation and locality in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed. The subsystem III consisted of river and river mouth ecosystems. The station P5 to P9 were located in river ecosystem while P10 and P11 were located at Phetchaburi and Bang Taboon river mouths, respectively. The characteristics of each station were described in Chapter three. This subsystem was the biggest area, it covered 1,468.37 sq.km. It was thus definite that the river had received the wastewater from many types of land use such as, agricultural, urban, industrial, recreation including the discharge from upstream. These reasons affected to the ecological relationships in each station that presented as follow:

4.5.1 Physical Parameters

The physical parameters were measured along the station P5 to P11 from downstream of Kaeng Krachan reservoir until approaching to the both Ban Laem and Bang Taboon river mouths. They contained as the following:

4.5.1.1 Depth

The averages of maximum depth of the seven stations in subsystem III varied from 0.35 ± 0.00 to 5.40 ± 4.04 metres. The highest average of water depth was 5.40 ± 4.04 metres at station P11 at the beginning of the wet season (June 2002) and the lowest average of maximum depth was 0.35 ± 0.00 metres at station P7 at the beginning of the wet season (June 2002) (Figure 4.40).

The maximum depths of station P5 to P9 (river stations) were high at the beginning of the dry season because there was flooding between October and November 2001. During this time the water volume was high in all waterbodies. Then the water depths decresed in the dry season and increased again at the beginning of the wet season. These values had tended to correlate to rainfall that had presented in Figure 4.5.

However, there was high discharge from the head water of Phetchaburi Watershed (Subsystem I) and Huai Pak Subwatershed (station P6). It increased water level in station P5 and P6. The Pollution Control Department reported that the maximum depths of the stations that were located in the river were slightly different within the seasons.

Considering station P7, Mae Prachan Subwatershed, is usually high discharge in the wet season. The amount water volume in this subwatershed is the main reason of the flood in Phetchaburi Province (Chulalongkorn University, 1994). According to the study of Sawetprawitchkul (1995), she reported that the most of flood run off in the Lower Watershed were routed from Huai Mae Prachan Subwatershed. Now, the reservoir is being constructed at the head water of this subwatershed. However, the water depth in this subwatershed was very low throughout the study period. At station P10 and P11, located at the river months of the watershed, the average of depth depended on sea level and each station's altitude. While the water depths of station P5, P8, P9 depended on the regulated flow of Kaeng Krachan reservoir and Phetchaburi Dam. However, the maximum depth in the wet season had tended to correlate within the seasons.

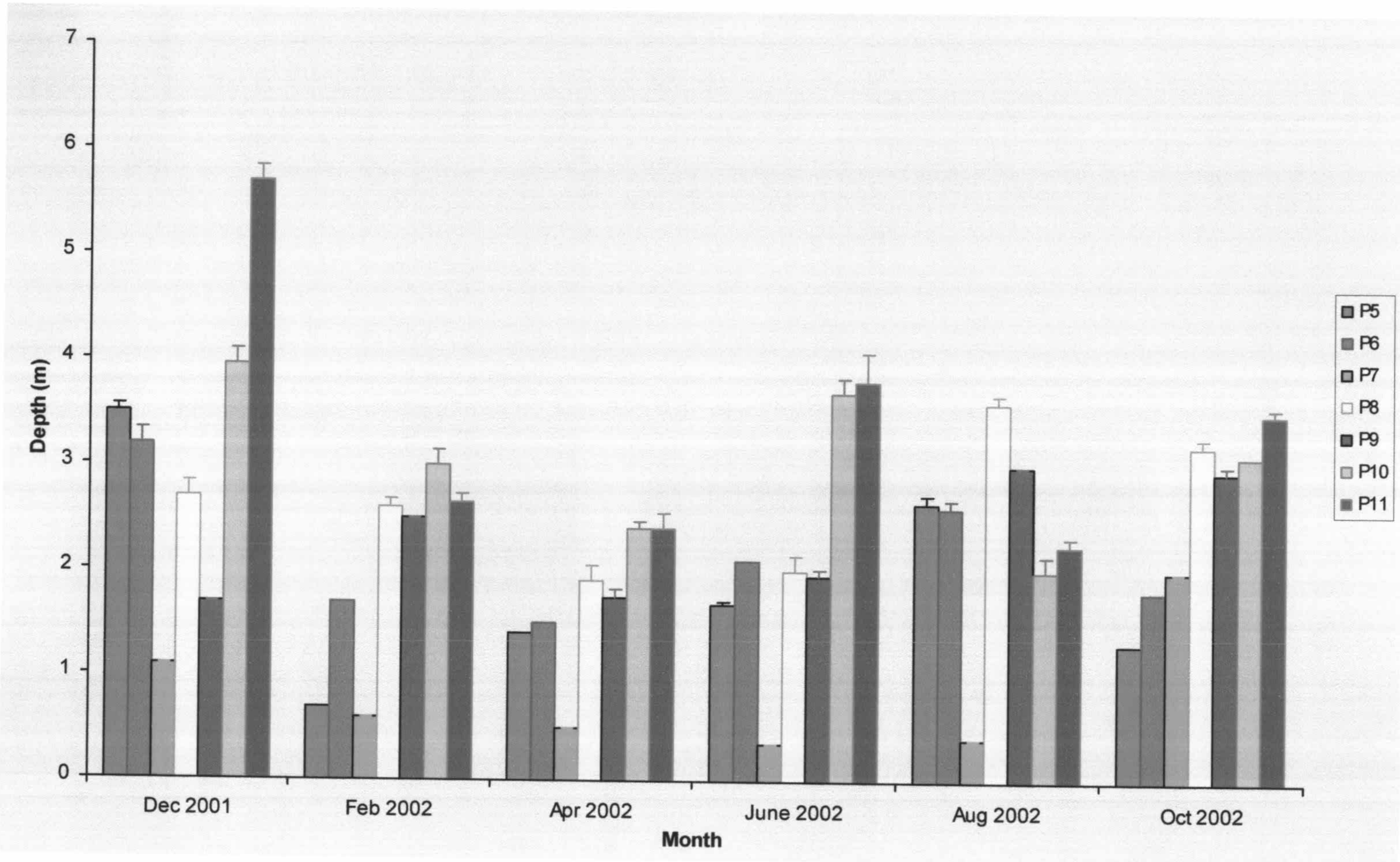


Figure 4.40 Average of depth in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary

4.5.1.2 Transparency Depth

The average values of transparency depth varied from 0.20 ± 0.00 to 2.80 ± 0.07 metres due to seasonal variation. The highest average of transparency depth was 2.80 ± 0.07 metres at station P5 at the beginning of the dry season (December 2001) and the lowest average of transparency depth was 0.20 ± 0.00 metres at station P10 at the end of the dry season and the middle of the wet season (April and August 2002) (Figure 4.41).

The averages values of transparency depth in most stations slightly related to the seasons. The transparency depth at station P5 and P6 were higher than other stations. At station P5, the river received the water volume from the Kaeng Krachan Reservoir. There was sedimentation in the reservoir, then the water from the outlet was decreased its sediment. In addition, the water was regulated flow and it was also decreased in flow rate. Then these might have reduced water turbidity of water. Considering station P6, was located in Huai Pak Subwatershed, the transparency depth was higher than other stations. Huai Pak Subwatershed has a rock base then the water that flows down from its small mountains is very clear. At station P7, the water level was low but its sediment was high, so the transparency depth was also low. While at station P8 and P9, the river flowed longer distances and received more wastewater from land, then their transparency depths were decreased.

On the other hand, transparency depth at station P10 and P11 was lower than the other stations that were located to the river. Station P10 and P11 were located at the river mouths of the watershed, had low values of transparency depth. These values related to the values of suspended solid. However, transparency depths in this subsystem were decreased from the river to the river mouths. The result of the study was the same as the studies of Chaleoisak (2000) and Pradisson (2000) who reported that the transparency depths was decreased from the river to the river mouth.

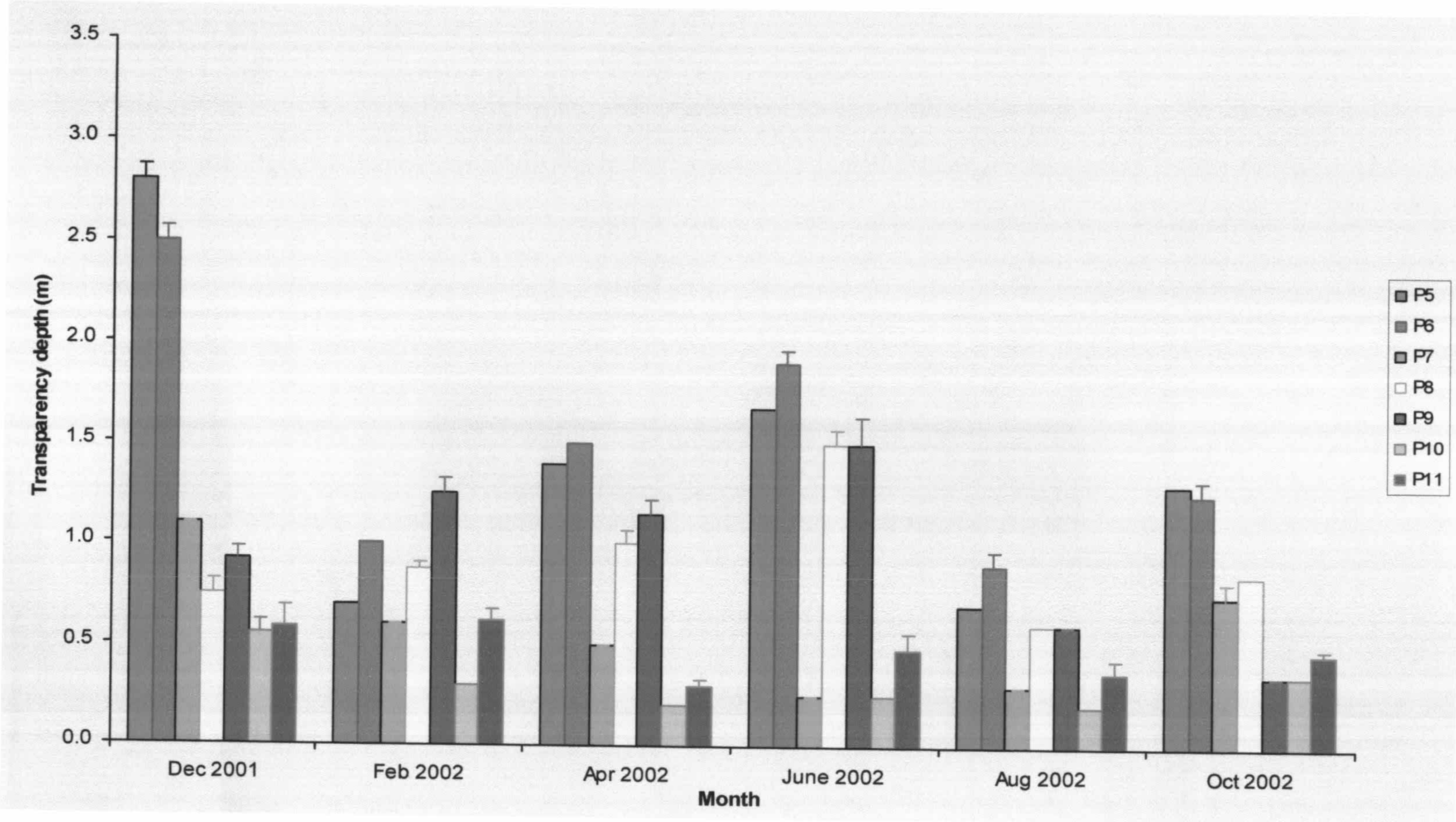


Figure 4.41 The transparency depth in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary

4.5.1.3 Water Temperature

The changes of the water temperature related to the seasons. The averages of water temperature ranged from 22.00 ± 0.71 °C to 34.00 ± 0.0 °C. The highest average of water temperature was 34.00 ± 0.00 °C at station P10 at the end of the dry season (April 2002) and the lowest average of water temperature was 22.00 ± 0.71 °C at station P10 at the beginning of the dry season (December 2001) (Figure 4.42).

The water temperature had tended to correlate to air temperature (Figure 4.5). The highest water temperatures in most stations were at the end of the dry season. While in December 2001, the weather was cool in all stations, the water temperatures in all stations were the lowest in this period. In addition at station P5 and P6 which were located near Kaeng Krachan National Park and surrounded by agricultural areas, the water temperatures in these stations were lower than other stations. However, the water temperature at station P5 was different significantly within the seasons at p = 0.05 (Table 5 in Appendix E). In addition, the water temperature at station P5 and P6 were lower than the other stations and was different significantly from other stations at the p = 0.05 (Table 23 in Appendix E). At station P10 and P11, the water temperature was related to air temperature and wind (the field notation). From the investigation, the water temperature in most stations was slightly different within the season.

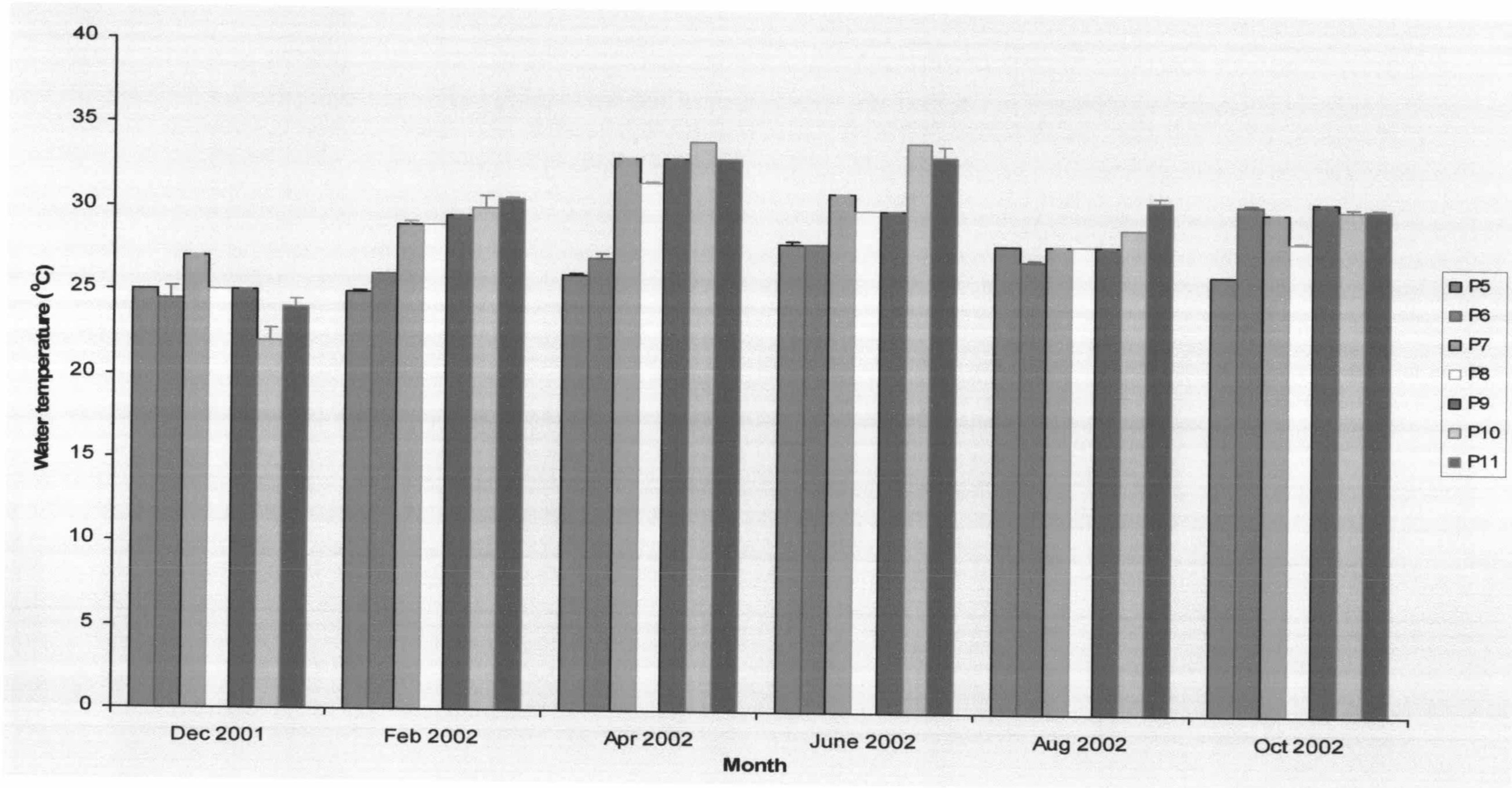


Figure 4.42 Average of water temperature in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary

4.5.1.4 Suspended Solid

The averages of suspended solid varied from 0.20 to 73.70 mg/l. The highest suspended solid was 73.70 mg/l at station P10 in the middle of the dry season (February 2002) and the lowest average of suspended solid was 0.20 mg/l at station P5 and P9 in the middle and at the end of the dry season (February and April 2002) (Figure 4.43).

The highest levels of suspended solid of station P5 to P9 (inland stations) were at the beginning of the dry season (December, 2001). Then the values decreased until the end of the dry season (April, 2002). The values of suspended solid increased again at the beginning of the wet season and remained high until the end of the wet season. Suspended solid had correlated within the seasons. Considering the suspended solid at station P10 and P11 (River mouths), were higher than other stations in the river and were different significantly at the $p = 0.05$ (Table 23 in Appendix E). However, these stations were located at downstream of the watershed, the water flowed from agricultural areas with high turbidity. The results were the same as the study of Pradissan (2000). She studied the suspended solid in the Chao Praya River, and reported that the suspended solid in downstream of the river were higher than in upstream. Furthermore, Lundin and Linden (1993) reported that the increase in human activities, particularly urbanization and agricultural areas has led to an increase in suspended solid content.

From the study, the suspended solid in subsystem III had tended to relate to the seasons. They had also increased from the river to the river mouth. Comparison to the study of Pollution Control Department (2001) they reported that the suspended solid in Phetchaburi River increased from the river and was the highest at the river mouth.

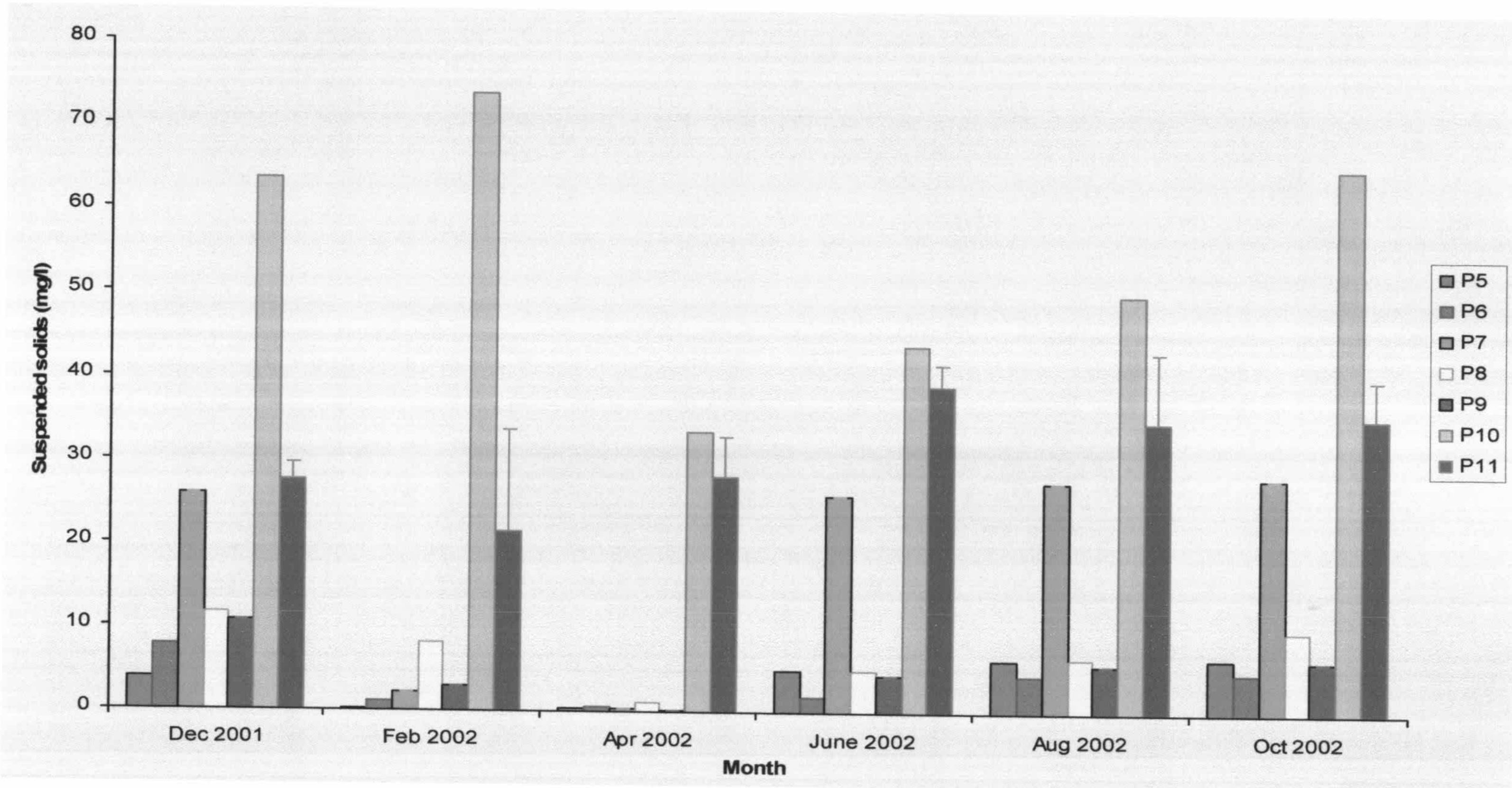


Figure 4.43 Average of suspended solid in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary

4.5.2 Chemical Parameters

The chemical parameters were measured along the station P5 to P11 from downstream of Kaeng Krachan reservoir until approaching to the both Ban Laem and Bang Taboon river mouths. They contained as the following:

4.5.2.1 pH

The averages of pH of the water varied from 6.00 ± 0.00 to 7.90 ± 0.00. The highest average of pH was 7.90 ± 0.00 at station P6 at the beginning of the dry season (December 2001) and station P7 at the end of the wet season (October 2002) and the lowest average pH was 6.00 ± 0.00 at station P5 and station P8 in the middle of the wet season (August 2002) (Figure 4.44).

The average of pH in all stations was slightly different within the seasons. However, the pH of station P7 was different significantly than other stations at the $p = 0.05$ (Table 13 in Appendix E). Station P7 was located downstream of Mae Prachan Subwatershed. Now, the reservoir is being constructed at the head water, the water level in the river was very low throughout the investigation except when it was raining.

At station P10 and P11 that were located at the Phetchaburi and Bang Taboon River Mouths, their pH values were the same trend. The pH values correlated to rainfall. These values might be increased because phytoplankton were in bloom, the pH values of the water usually slightly increased (Graham and Wilcox, 2000).

The pH values of the water at all seven stations in subsystem III were in the range of the standard of surface water quality in Thailand (Pollution Control Department, 1997). The pH of the water can control the activities of all living organisms in natural water resources. The optimum pH, that is suitable for all living organisms in water, is in the range between 6 and 8 (Gajaseni, 1996).

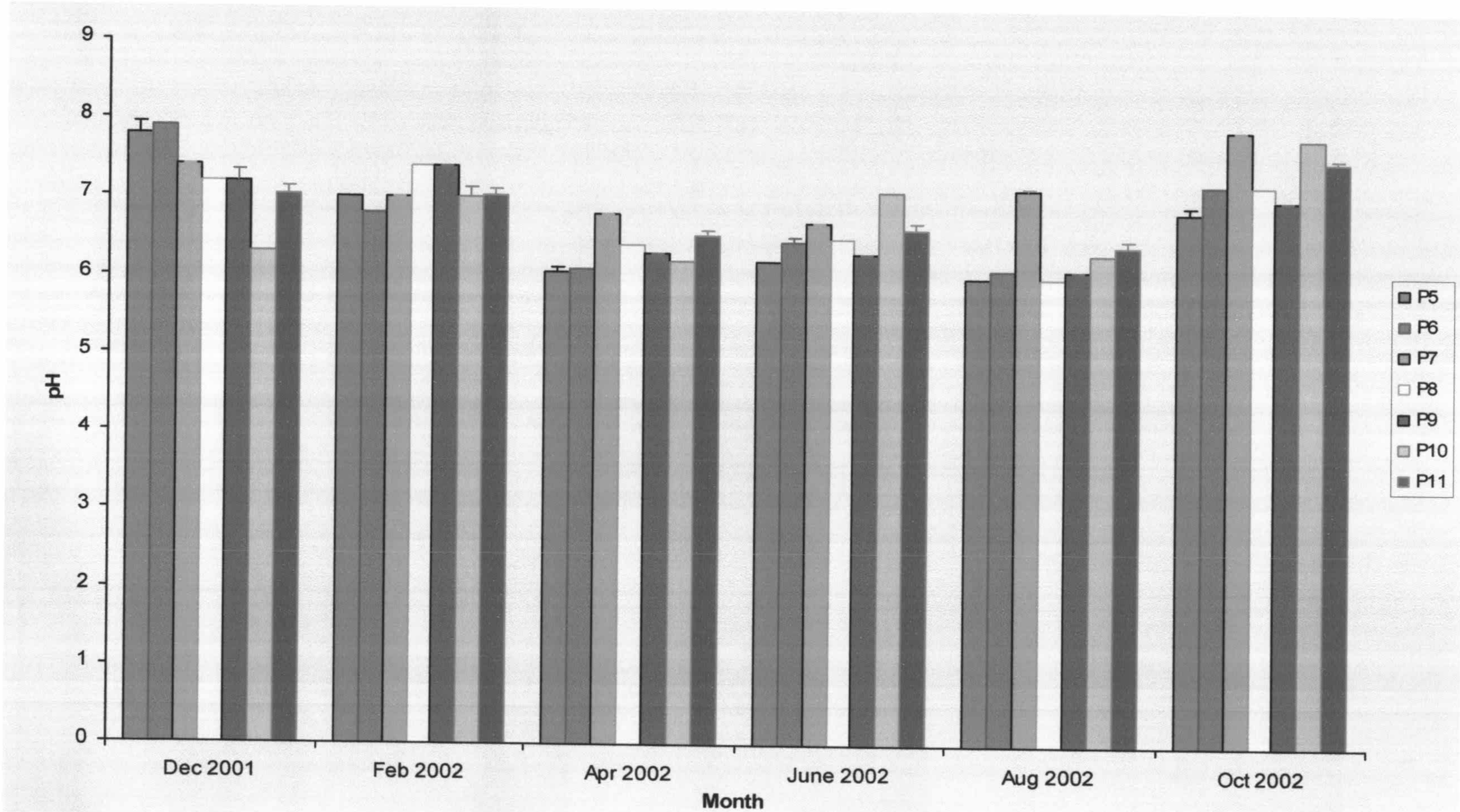


Figure 4.44 Average of pH in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary

4.5.2.2 Dissolved Oxygen

The averages of dissolved oxygen varied from 3.65 ± 0.07 to 8.20 ± 0.28 mg/l. The highest average of dissolved oxygen was 8.20 ± 0.28 mg/l at station P5 at the beginning of the dry season (December 2001) and the lowest average of dissolved oxygen was 3.65 ± 0.07 mg/l at station P10 in the middle of the dry season (February 2002) (Figure 4.45).

The average values of dissolved oxygen in all stations decreased in the middle of the dry season (February and April 2002). However, dissolved oxygen levels of all stations were not different within the seasons.

Dissolved oxygen at station P5 and P6 were higher than other inland stations (station P7, P8 and P9). Station P5 was located under the Kaeng Krachan Reservoir. The streamflow in the wet season was higher than in the dry season. Besides, station P6 was located in Huai Pak Subwatershed. The water flows from the small mountains down to the station P6 before flowing into the Phetchaburi River. Then dissolved oxygen in this station was high. On the other hand, the dissolved oxygen at station P7 was slightly lower than station P5 and P6. Although station P7 was located at the downstream of Mae Prachan Subwatershed, the streamflow was slow and also had low water volume throughout the investigation. Then dissolved oxygen was slightly decreased. Besides, station P8 and P9 were located in downstream of the watershed and streamflow was slow down. Then dissolved oxygen slightly decreased in both stations. The average values of dissolved oxygen at station P10 and P11 were lower than other stations and were different significantly at the $p = 0.05$ (Table 23 in Appendix E). Station P10 and P11 were located at the river mouths of the watershed. These areas were disturbed by many factors such as suspended solid, turbidity and pH. These factors affected the values of dissolved oxygen.

In addition, in the dry season, the runoff from inland was slow down then dissolved oxygen also slightly decreased. Considering the river mouth areas have high wastewater and sediments, then there is high rate of decomposition. These might be decreased dissolved oxygen at the areas of station P10 and P11. However, the values of dissolved oxygen at all stations in subsystem III were in the normal range of dissolved oxygen according to the standard of surface water quality (Pollution Control Department, 1997). It was accepted the dissolved oxygen at Phetchaburi River Mouth (station P10) that was lower than the third category of the standard water quality.

On the other hand, there must be concern about this value because oxygen is essential to all forms of aquatic life. The level of dissolved oxygen, that is suitable for living organisms in water, is 5 mg/l.

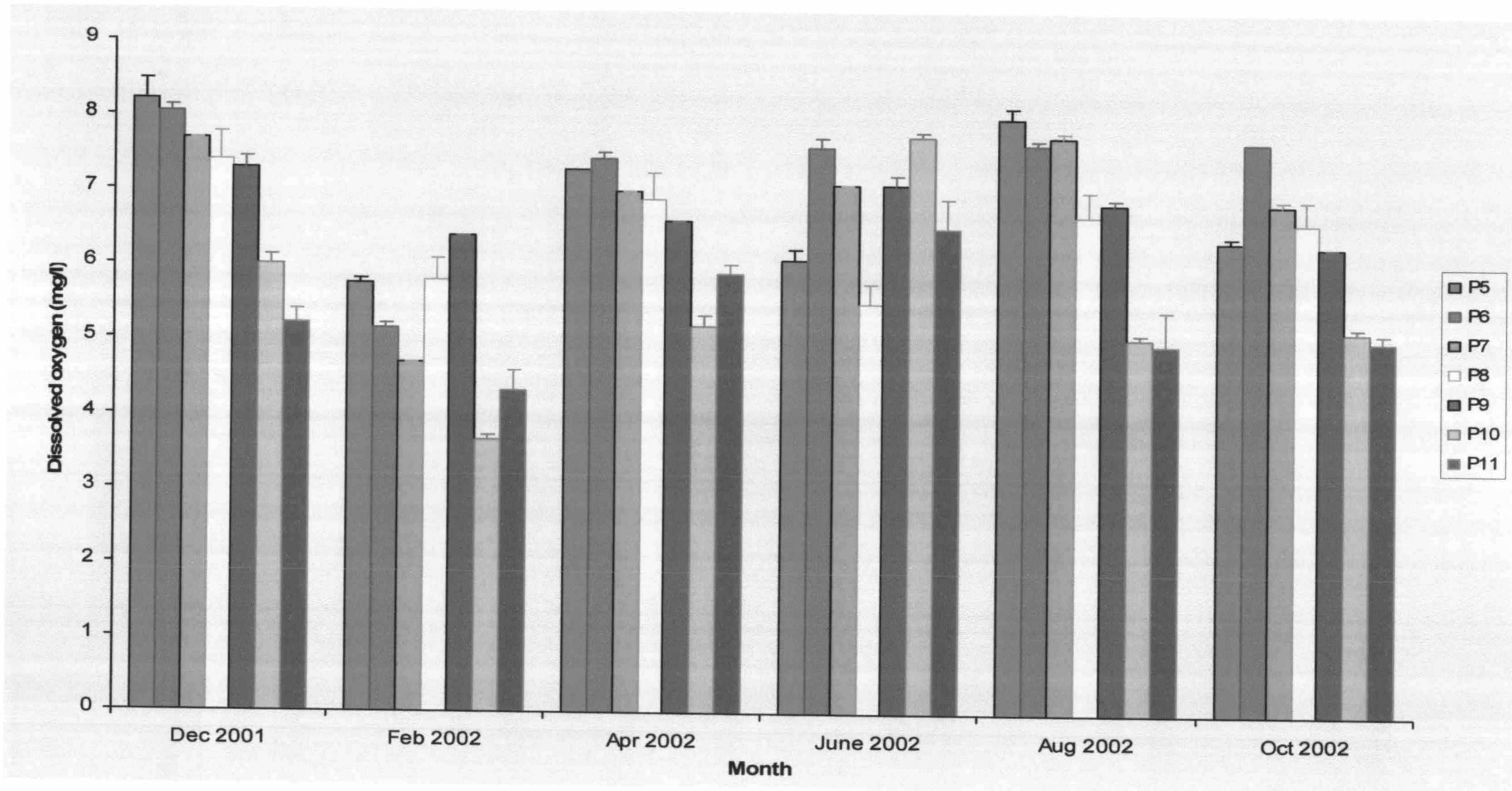


Figure 4.45 Average of dissolved oxygen in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary

4.5.2.3 Salinity

The averages of salinity varied from ND to 23.33 ± 2.58 psu The highest average of dissolved oxygen was 23.33 ± 2.58 psu at station P11 in the middle of the dry season (February 2002) and the lowest average was 0.00 psu at all inland stations throughout the year (December 2001 to October 2002) (Figure 4.46).

The values of salinity were detected at station P10 and P11 and varied from 1.00 to 24.00 psu. The values of salinity in the dry season were higher than in the wet season at both stations. In the wet season, the water flowed from the river and its volume could reduce the values of salinity. For this study, the sampling method was set to study the recovery of the watershed (ecosystem resilience), then the sampling was collected 1 - 2 hours after the beginning of the low tide.

The salinity of both stations were significantly different within the seasons at the p = 0.05 (Table 23 in Appendix E).

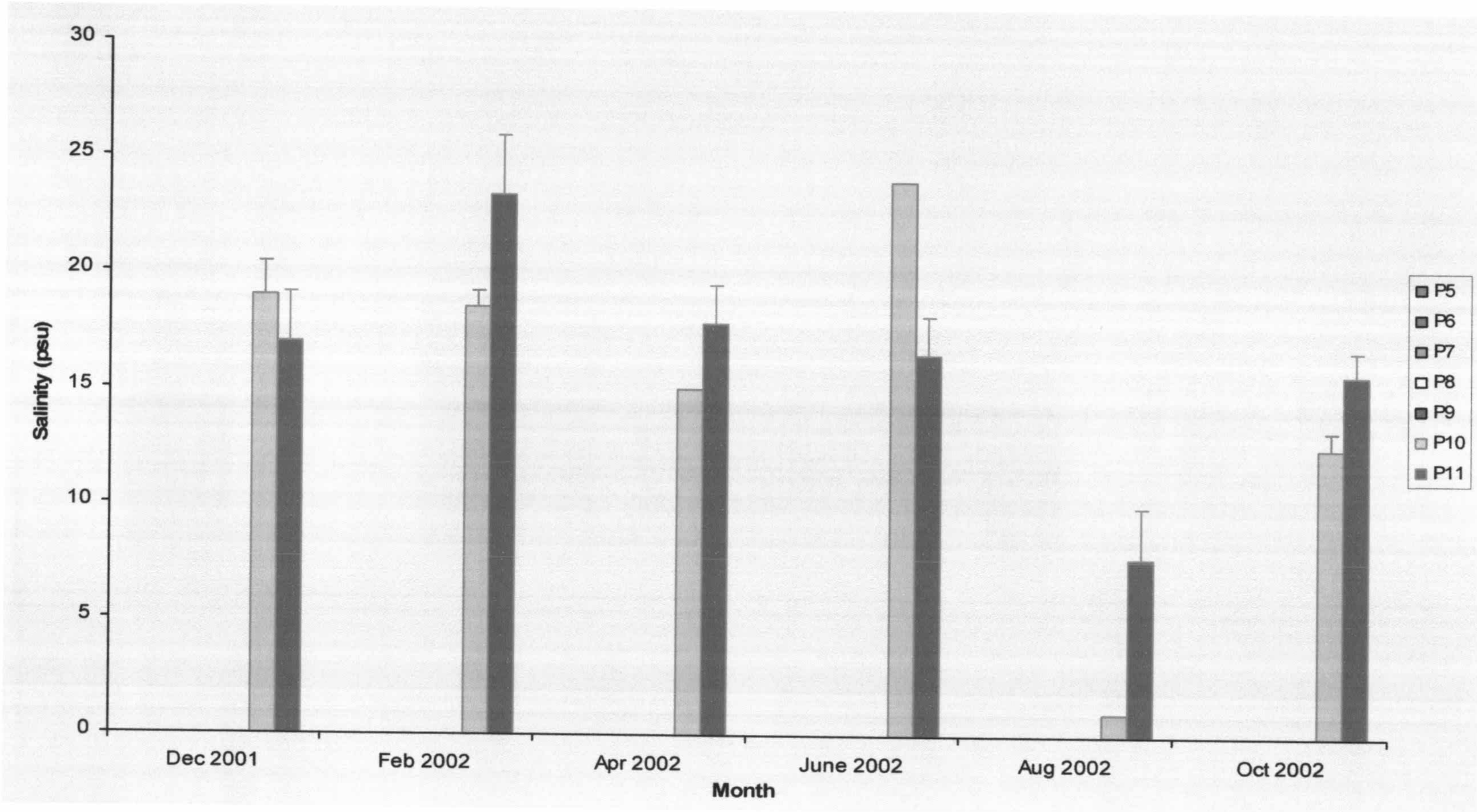


Figure 4.46 Average of salinity in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary

4.5.2.4 Nitrate-Nitrogen

The averages of nitrate-nitrogen concentration varied from ND ± 0.16 to 186.11 ± 0.26 ug/l The highest average of this value was 186.11 ± 0.26 ug/l at station P10 in the middle of the wet season (August 2002) and the lowest could not be detected at station P11 in the middle of the dry season (February 2002) (Figure 4.47).

At station P7 (Mae Prachan Subwatershed), nitrate-nitrogen concentration was high. The level of water in this river was very low and high turbid. Then the volume of water was low. Nitrate-nitrogen concentration at P7 related to suspended solid. In addition, this subwatershed had high percentage of agricultural areas (Figure 4.58). These reasons could increase the concentration of nitrate-nitrogen in the water. On the other hand, at station P5, P6, P8 and P9, nitrate-nitrogen concentrations had tended to correlate to rainfall (Figure 4.1).

The average of nitrate-nitrogen concentration in station P10 and station P11 were higher than other inland stations because station P10 and station P11 were located at the Ban Laem and Bang Taboon River Mouths, respectively. The zone of the river mouths have high nutrient concentrations that wash down from inland. The water flows from upstream to downstream, and then it passes through many land use types especially, the aquacultural farms surrounding the river mouths.

From the results, it found that the average nitrate-nitrogen concentration at all stations of subsystem III was different significantly within the seasons at the $p = 0.05$ (Table 13 in Appendix E). Promthong (1999) reported that the nitrate-nitrogen concentration was highest in the dry season at the Tha Chin estuary, Samut Sakhon Province. Comparison with this study, nitrate-nitrogen concentration had tended to correlate to rain fall. There was highly rainfall and rain occurred all year (Pollution control Department, 2003). The catchment area had an increase of nitrate-nitrogen concentration from soil erosion. In addition, rain could wash down from the agricultural areas along the river banks. Especially, from the aquacultural areas at the river mouths (Pollution Control Department, 2003).

The average of nitrate-nitrogen concentration at all seven stations in subsystem III did not exceed 5 mg/l that is the maximum figure set as the standard of surface water quality in Thailand (Pollution Control Department, 1997)

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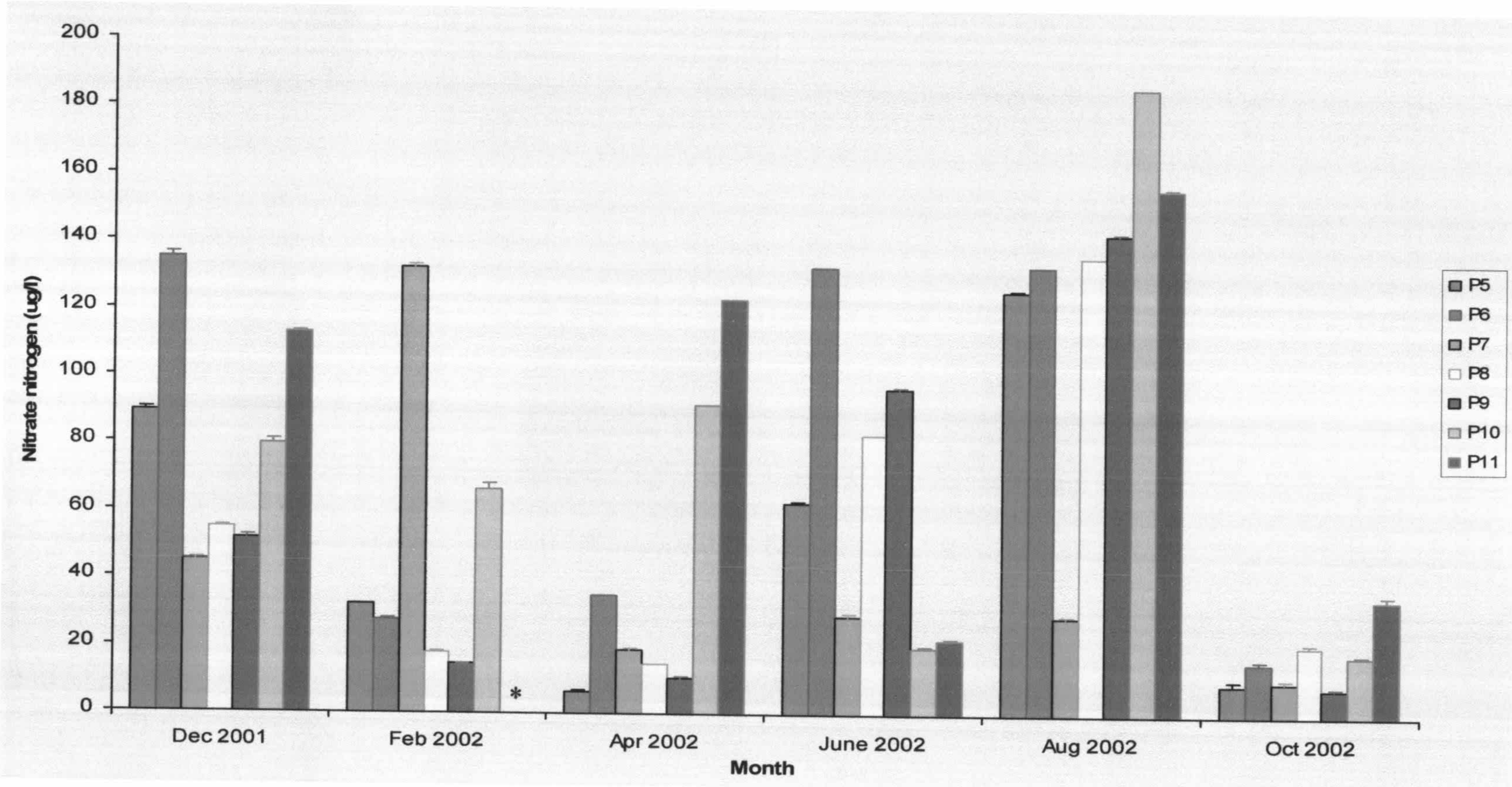


Figure 4.47 Average of nitrate-nitrogen in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary, * = could not be detected

4.5.2.5 Nitrite-Nitrogen

The averages of nitrite-nitrogen concentration ranged from 0.04 ± 0.00 to 65.65 ± 21.40 ug/l. The highest average of the value was 65.65 ± 21.40 ug/l at station P11 in the middle of the dry season (February 2002) and the lowest was 0.04 ± 0.00 ug/l at station P10 at the end of the wet season (October 2002) (Figure 4.48).

Nitrite-nitrogen concentrations at station P5 to P9 had tended to correlate within the seasons and the rate of rainfall (Figure 4.5). Their concentrations were low in the dry season and increased at the beginning of the wet season. However, at station P7 nitrite-nitrogen was higher than other stations that were located inland except in June 2002. Mae Prachan Subwatershed (station P7) had high suspended solid and its streamflow was turbid (Figure 4.44). Nitrite-nitrogen concentration increases when there is high suspended solid (Goldman and Horne, 1994).

Nitrite-nitrogen concentrations at the river mouths (stations P10 and P11) were higher than at the inland stations (stations P5 to P9) and were significantly different at the $p = 0.05$ (Table 13 in Appendix E). Nitrite-nitrogen concentration had a trend to correlate to suspended solid concentration. At the river mouths, the suspended solid was very high. In addition, the wind increased suspended solid in these areas. The average of nitrite-nitrogen concentration in subsystem III was significantly different within the seasons at the $p = 0.05$ (Table 13 in Appendix E). However, the average nitrite-nitrogen concentration of all seven stations in subsystem III did not exceed the standards surface water quality in Thailand which must not exceed 500 ug/l (National Environment Board, 1994).

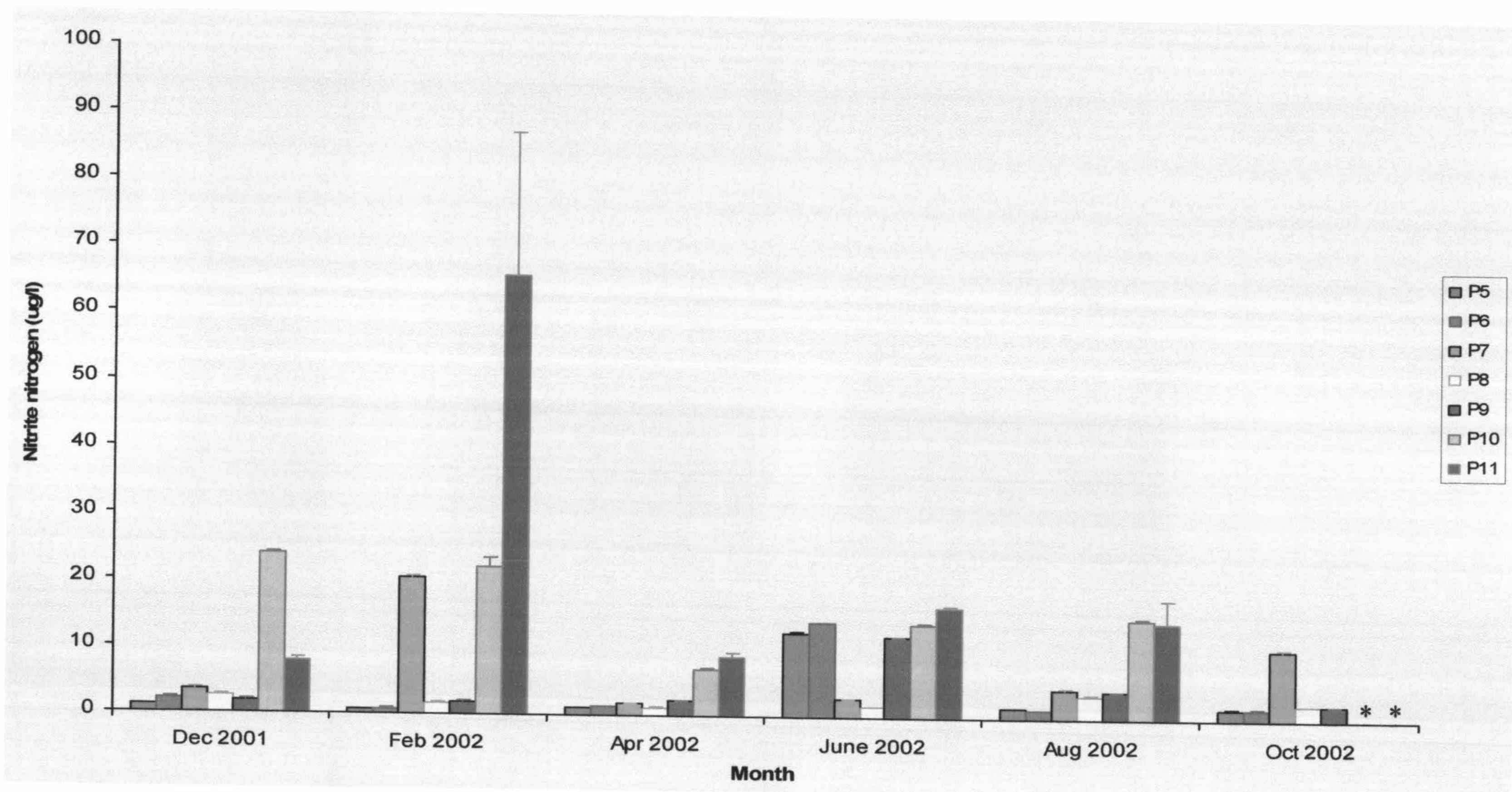


Figure 4.48 Average of nitrite-nitrogen in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary, * = could not be detected

4.5.2.6 Ammonium-Nitrogen

The averages of ammonium-nitrogen concentration varied from ND to 155.05 ± 7.82 ug/l. The highest average ammonium-nitrogen concentration was 155.05 ± 7.82 ug/l at station P11 at the end of the wet season (October 2002) and could not be detected at station P6 in the middle of the dry season (February 2002) and station P8 at the beginning of the wet season (June 2002) (Figure 4.49).

The average ammonium-nitrogen concentration at station P5 to P9 had tended to correlate within the seasons. Ammonium-nitrogen concentrations in the wet season were higher than in the dry season. In the dry season, the streamflow is low then the ammonium-nitrogen concentration increases by excretion of aquatic lifes and drainage water. Contrast to the wet season, ammonium-nitrogen concentration increases by rainfall that washes down nutrients from land to the river.

At the two river mouths (station P10 and P11), the average ammonium-nitrogen concentrations was high and significantly different within the seasons at the $p = 0.05$ (Table 10; 11 in Appendix E). These two stations had high levels of suspended solid, that could affect to increase ammonium-nitrogen concentration. In addition, the waterbody received ammonium-nitrogen from water that washed down the nutrients from aquacultural farms surrounding the areas of two river mouths.

The average ammonium-nitrogen concentration in subsystem III was significantly different within the seasons at the $p = 0.05$ (Table 13 in Appendix E). However, the ammonium-nitrogen concentration at all seven stations in subsystem III did not exceed 500 ug/l, that is the maximum figure set as the standard of surface water quality in Thailand (Pollution Control Department, 1997).

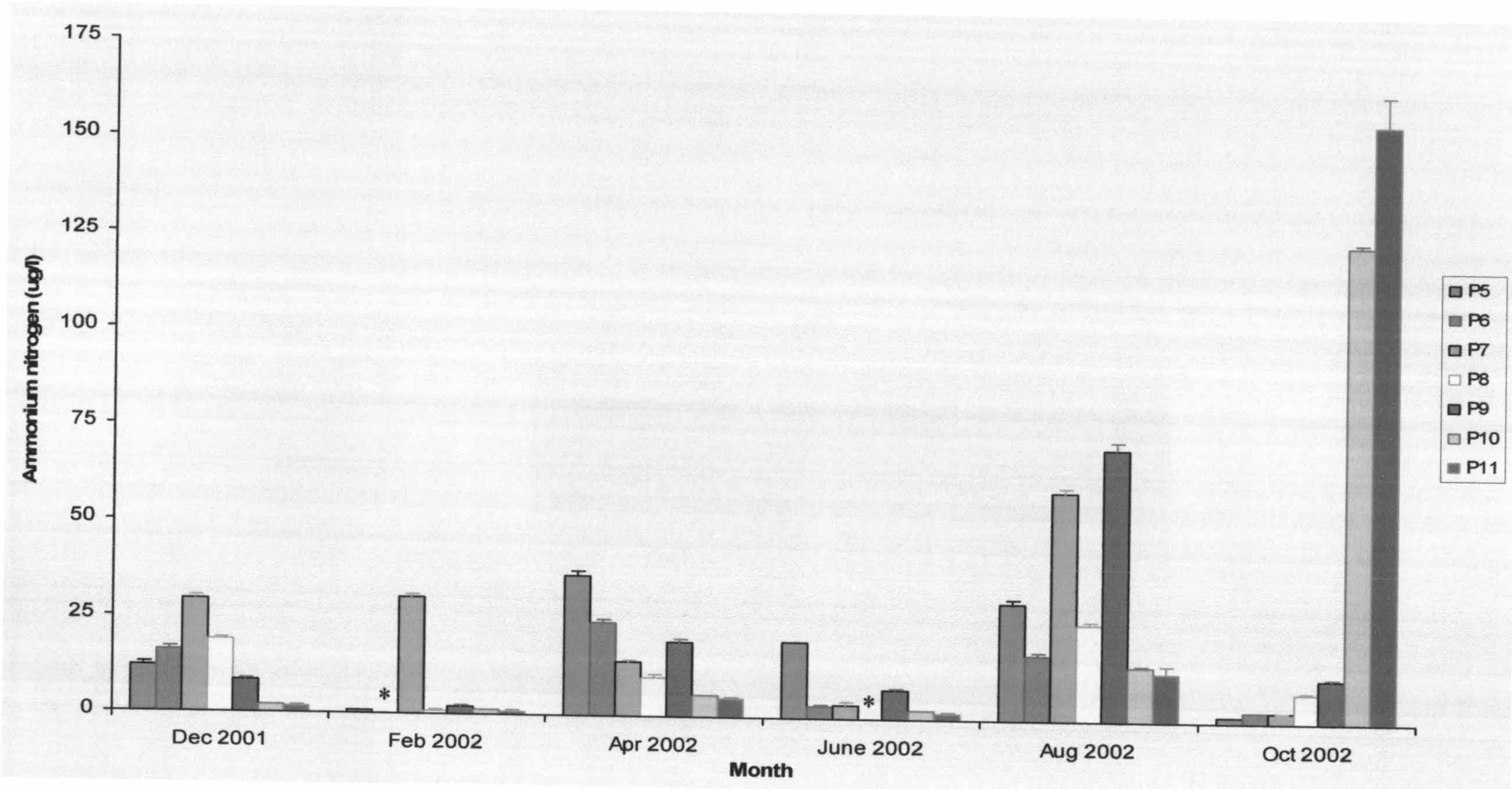


Figure 4.49 Average of ammonium-nitrogen in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary, * = could not be detected

4.5.2.7 Phosphate-Phosphorus

The averages of Phosphate-phosphorus concentration ranged from ND to 126.52 ± 1.08 ug/l. The highest concentration was 126.52 ± 1.08 ug/l at station P10 at the beginning of the dry season (December 2001) Phosphate-phosphorus concentration could not be detected at station P5 and P6 at the same period. In addition, they could not be detected at all inland stations (station P5 to P9) at the end of the dry season (April 2002) (Figure 4.50).

The average Phosphate-phosphorus concentration of inland stations (P5 to P9) had tended to correlate within the seasons. The average Phosphate-phosphorus concentration in the dry season was higher than in the wet season. Especially, the average Phosphate-phosphorus concentrations at station P5 and P6 were different significantly within the seasons at the $p = 0.05$ (Table 5 and 6 in Appendix E). In the dry season, the volume of water decreased, and then the wastewater from household and agricultural areas would increase Phosphate-phosphorus concentration. Phosphate-phosphorus concentration at station P7 might be affected by suspended solid. The water level in this station was low throughout the investigation and it was highly turbid. Beside, station P8 was located in agricultural areas then the drainage water from these areas could wash fertilizers from land into the river. Considering station P9 was located at urban area then its Phosphate-phosphorus concentration was higher than other inland stations. Wastewater from household can increase Phosphate-phosphorus in waterbody.

At the river mouths (station P10 and P11), Phosphate-phosphorus concentration were higher than the concentration of all inland stations. Phosphate-phosphorus concentration was high throughout the investigation. The river mouths were the outlets of the watershed then they received all drainage water from the whole watershed that could have different effects to nutrient loading in the waterbodies. Pollution Control Department (2001) reported that the Phosphate-phosphorus concentration at the Phetchaburi river mouth was in the range 4.0 to 80.0 ug/l

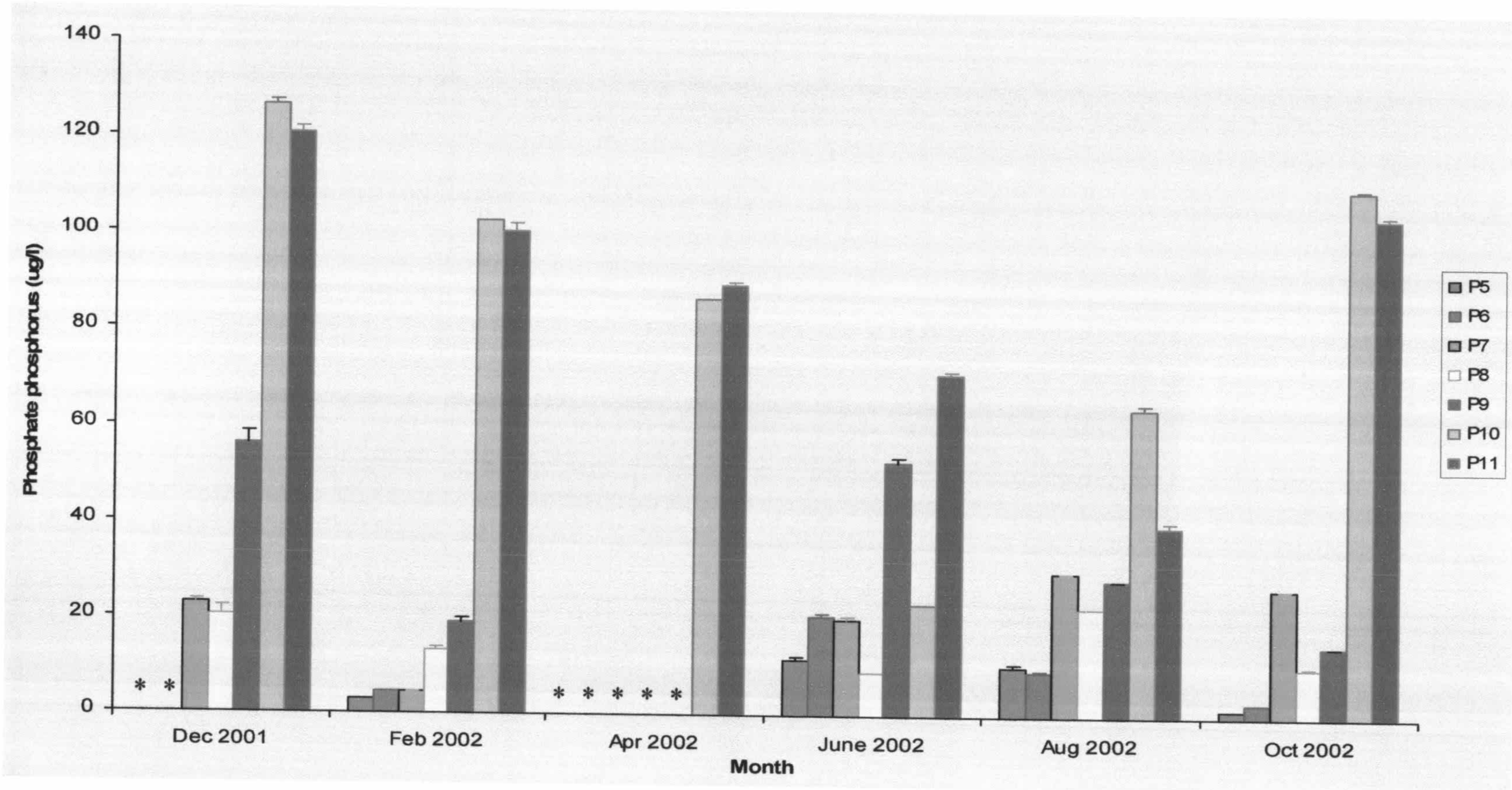


Figure 4.50 Average of phosphate-phosphorus in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary, * = could not be detected

4.5.2.8 Silica-Silicon

The averages of silica-silicon concentration ranged from 0.40 ± 0.01 to 24.87 ± 0.07 mg/l. The highest average of this value was 24.87 ± 0.07 mg/l at station P7 in the middle of the dry season (February 2002) and the lowest value was 0.40 ± 0.01 mg/l at station P10 in the middle of the dry season (February 2002) (Figure 4.51).

The silica-silicon concentration of inland stations had tended to correlate to rainfall (Figure 4.5). In the wet season, the high rate of rock and soil weathering can increase silica concentration into waterbody (Wetzel, 2001). The average silica-silicon concentrations at station P5, P6, P8 and P9 were significantly different within the seasons at the $p = 0.05$ (Table 5; 6; 8 and 9 in Appendix E). Considering station P7, its silica-silicon concentration was higher than other stations. This might be affected by construction of the Mae Prachan reservoir. In addition silica-silicon concentration is usually high in the area that is high soil erosion. Station P7 had high suspended solid. Comparison to the silica-silicon concentration of the drainage to natural waters, it is less variable than many of the other major inorganic constituents (Wetzel, 2001). Silica concentration of natural freshwater most commonly ranges from 1.00 to 30.00 mg/l (APHA, AWWA and WEF, 1998). At the river mouths, both stations P10 and P11 had lower silica-silicon concentration than all inland stations. In the areas of the river mouths, the plankton community presented a high density of diatom. Silica is very essential for diatom growth (Graham and Wilcox, 2000). Diatoms are major phytoplankton in marine ecosystem. In addition, there were diatom blooms in both river mouths during the study period. Then these might be decreased silica-silicon concentration. However, silica concentration in the areas of the whole watershed has tended to be sufficient. Silica flows from inland to the river mouth. Especially, silicon increases rapidly when diatoms die off (Wetzel, 2001). Then it might have been affected a change in silica-silicon concentration.

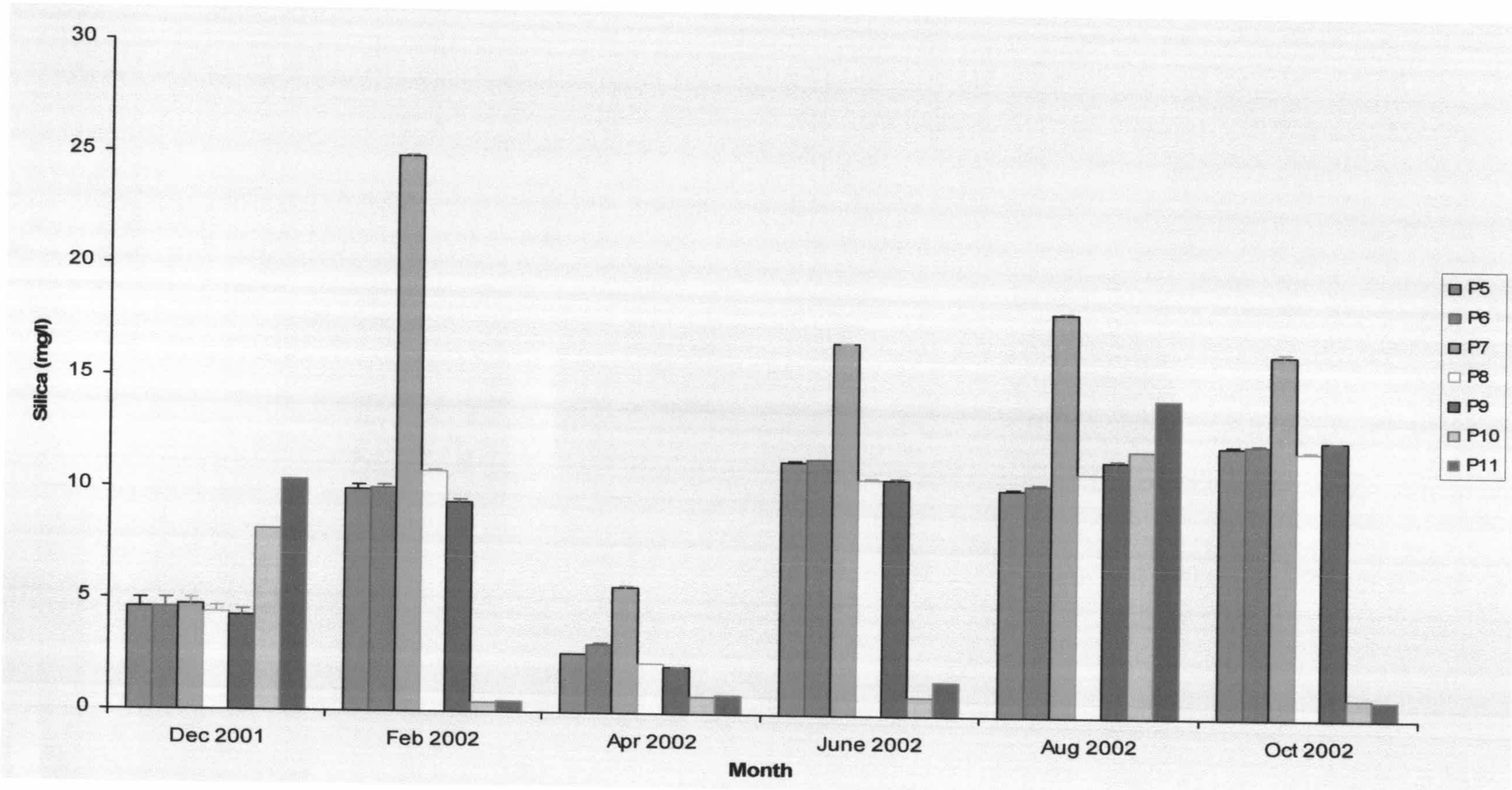


Figure 4.51 Average of silica-silicon concentration in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary

4.5.3 Biological Parameters

For biological parameter, phytoplankton is very important to an aquatic ecosystem. Therefore, phytoplankton dynamics are examined in order to analyze the relationship to ecological parameters due to seasonal variation as well as land use activities. Thus, the species composition, phytoplankton density and chlorophyll *a* concentration in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed were indicated as follow;

4.5.3.1 Species Composition

A study of biodiversity of phytoplankton was conducted in order to analyze the ecological condition of water existing subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) from December 2001 to October 2002. Phytoplankton were classified into 7 divisions, 7 classes 13 order, 32 families, 51 genera and 54 species including 3 unidentified species. Following Rott's 1981 classifications, this investigation found that the total phytoplankton consisted of 7 groups in subsystem III, Diatomophyceae was the most diverse family with 28 spp. There were 7 species of Cyanophyceae and 5 species of Dinophyceae. Eight species of Chlorophyceae were found. Zygnemaphyceae had 3 species, 2 species of Euglenophyceae and only one species of Chrysophyceae was found (Table 4.10).

In comparison with other researches in limnology, this study was the same as Peerapornpisal, Pektong, Waiyaka and Promkutkew (2000) who reported that diatom was the majority of phytoplankton in Mae Sa Stream, Doi Suthep-Pui National Park, Chiang Mai. Furthermore, Noinamsai (2000) reported that diatom was the major group in the lotic ecosystem of the Lam Phra Phloeng Watershed and the most important influence on phytoplankton biodiversity was temperature in the watershed. Contrasting with the study of Chaleoisak (2000), it was reported that there were 156 species of phytoplankton in Tha Chin River. Green algae was the most abundant group throughout the year. While Phromthong (1999) reported that diatom was the dominant phytoplankton in the dry season and blue-green algae and green algae were abundance in rainy season in Tha Chin River Mouth, Samut Sakhon Province.

Table 4.10 List of species of phytoplankton survey in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Phytoplankton species		
Cyanophyceae	*Anabaena* sp.1	*
	Lyngbya sp.	*
	Merismopedia sp.	*
	Microcystis aeruginosa	*
	Oscillatoria sp.	*
	Spirulina sp.	**
	Tolypothrix sp.	**
Dinophyceae	*Ceratium* sp.	*
	Dinophysis sp.	*
	Peridinium sp.	*
	Prorocentrum sp.	*
	Protoperidinium sp.	*
Diatomophyceae	*Aulacoseira* sp.	*
	Bacillaria sp.	*
	Bacteriastrum sp.	*
	Chaetoceros sp.2	*
	Coscinodiscus sp.	*
	Cyclotella sp.	*
	Cymbella sp.	*
	Diploneis sp.	*
	Epithemia sp.	*
	Eucampia sp.	*
	Fragilaria sp.1	*
	Gomphonema sp.	*
	Gyrosigma sp.	*
	Navicula sp.1	*
	Nitzschia sp.1	*
	Odontella sp.	*
	Pleurosigma sp.	*
	Pseudonitzschia sp.	*
	Rhizosolenia sp.	*
	Skeletonema sp.	*
	Surirella sp.	*
	Synedra sp.	*
	Tabellaria sp.	*
	Thalassionema sp.	*
	Thallassiosira sp.	*
	Triceratium sp.	*
	Unidentified species 1	*
	Unidentified species2	*
Chrysophyceae	*Dinobryon* sp.	*
Chlorophyceae	*Ankistrodesmus* sp.	*
	Botryococcus braunii	***
	Crucigenia sp.	*
	Pediastrum sp.1	*
	Scenedesmus sp.1	*
	Spirogyra sp.	*
	Staurodesmus sp.	*
	Unidentified species 3	*
Zygnemaphyceae	*Closterium* sp	*
	Cosmarium sp.1	*
	Staurastrum sp.1	*
Euglenophyceae	*Euglena* sp.	*
	Phacus sp.	*

Note: Unit of phytoplankton density, * = cell, ** = filament, *** = colony

4.5.3.2 Dominant Species

Subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of the Phetchaburi Watershed had 7 stations. The dominant species of station P5 (upstream of Phetchaburi River from Kaeng Krachan Reservoir) were *Oscillatoria* sp., *Tabellaria* sp., *Navicula* sp.1, *Nitzschia* sp., *Surirella* sp. and *Microcystis* sp. The dominant species of station P6 were *Oscillatoria* sp., *Tabellaria* sp., *Navicula* sp.1 and *Surirella* sp. The dominant species of station P7 (proposed reservoir in Mae Prachan Subwatershed, Phetchaburi Watershed) were *Oscillatoria* sp., *Navicula* sp.1, *Tabellaria* sp. and *Surirella* sp. The dominant species of station P8 (agricultural areas at downstream, Phetchaburi River) were *Oscillatoria* sp., *Navicula* sp.1, *Surirella* sp. and *Tabellaria* sp. The dominant species of station P9 (domestic and industrial areas, Amphoe Maung, Phetchaburi Province) were *Oscillatoria* sp., *Surirella* sp., *Navicula* sp.1, *Tabellaria* sp., *Pleurosigma* sp. and *Nitzschia* sp. The dominant species of station P10 and P11 (river mouth area at Ban Laem and Bang Taboon Estuary) were *Coscinodiscus* sp., *Oscillatoria* sp., *Rhizosolenia* sp., *Chaetoceros* sp.2, *Skeletonema* sp., *Cyclotella* sp. and *Gyrosigma* sp. *Oscillatoria* was found in every station and *Navicula* was the dominant species in almost stations The dominant phytoplankton species are shown in Figure 4.52.

Comparison to another study, Hourban (1997) reported that the dominant species in Bangpakong River were *Coscinodiscus* sp., *Odontella* sp., *Nitzschia* sp. in the group of diatom and *Oscillatoria* sp.in blue-green algae group. This study found that *Coscinodiscus* were dominantat both Ban Laem and Bang Taboon River Mouths throughout the year. The number of phytoplankton species related to the seasons. In subsystem III, the number of phytoplankton species in the wet season was higher than in the dry season. Along downstream of the watershed, the water flowed slowly, so the conditions were suitable for aquatic life (Figure 4.53). In addition, nutrient concentration was enriching in the wet season. However, at station P5 (upstream of Phetchaburi River from Kaeng Krachan Reservoir) and P6 (propose reservoir in Huai Pak Subwatershed, Phetchaburi Watershed) the water flowed quickly like in upstream areas, so it affected a decrease in phytoplankton species. This study found that the numbers of species at the river mouths were higher than the all inland stations.

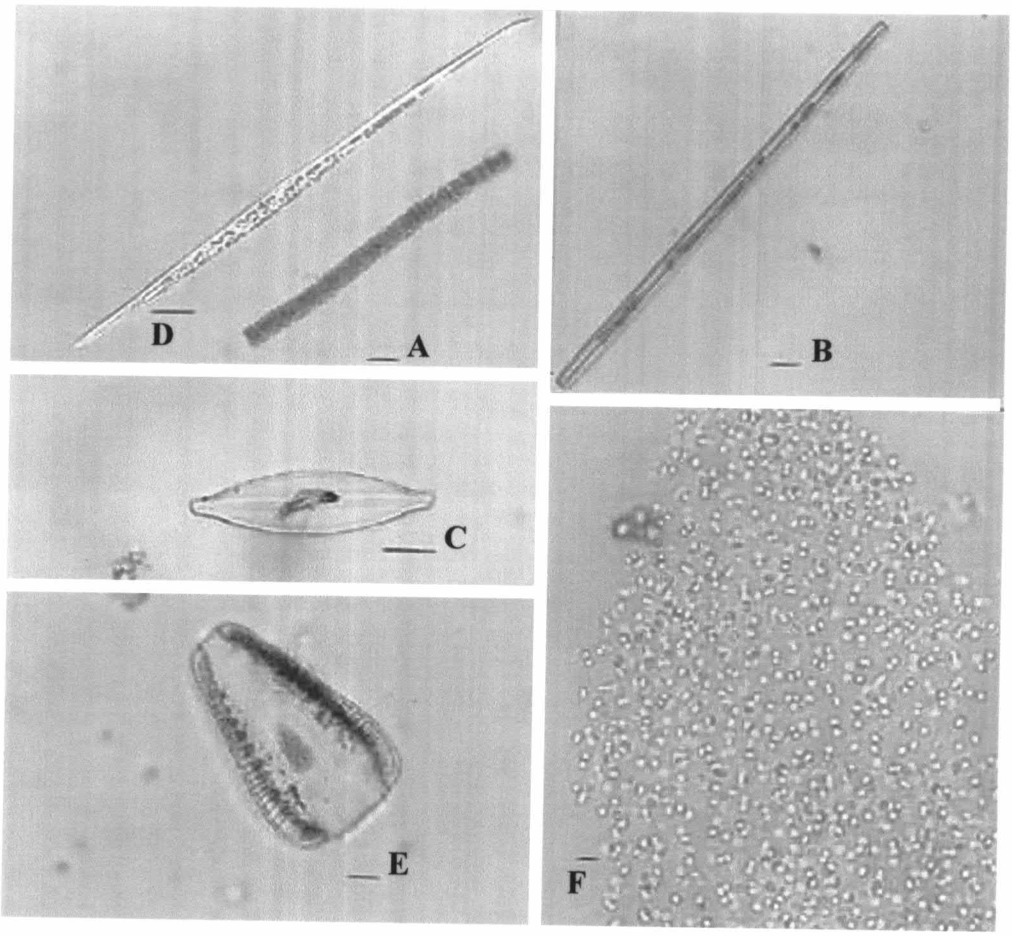


Figure 4.52 Dominant phytoplankton species in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed, *Oscillatoria* sp. (A), *Tabellaria* sp. (B), *Navicula* sp. (C), *Nitzschia* sp. (D), *Surirella* sp.(E), *Microcystis* sp.(F), *Gyrosigma* sp.(G), *Pleurosigma* sp. (H), *Coscinodiscus* sp. (I), *Rhizosolenia* sp. (J), *Chaetoceros* sp. (K), *Skeletonema* sp. (L) and *Cyclotella* sp. (M), scale bar — = 10 micron

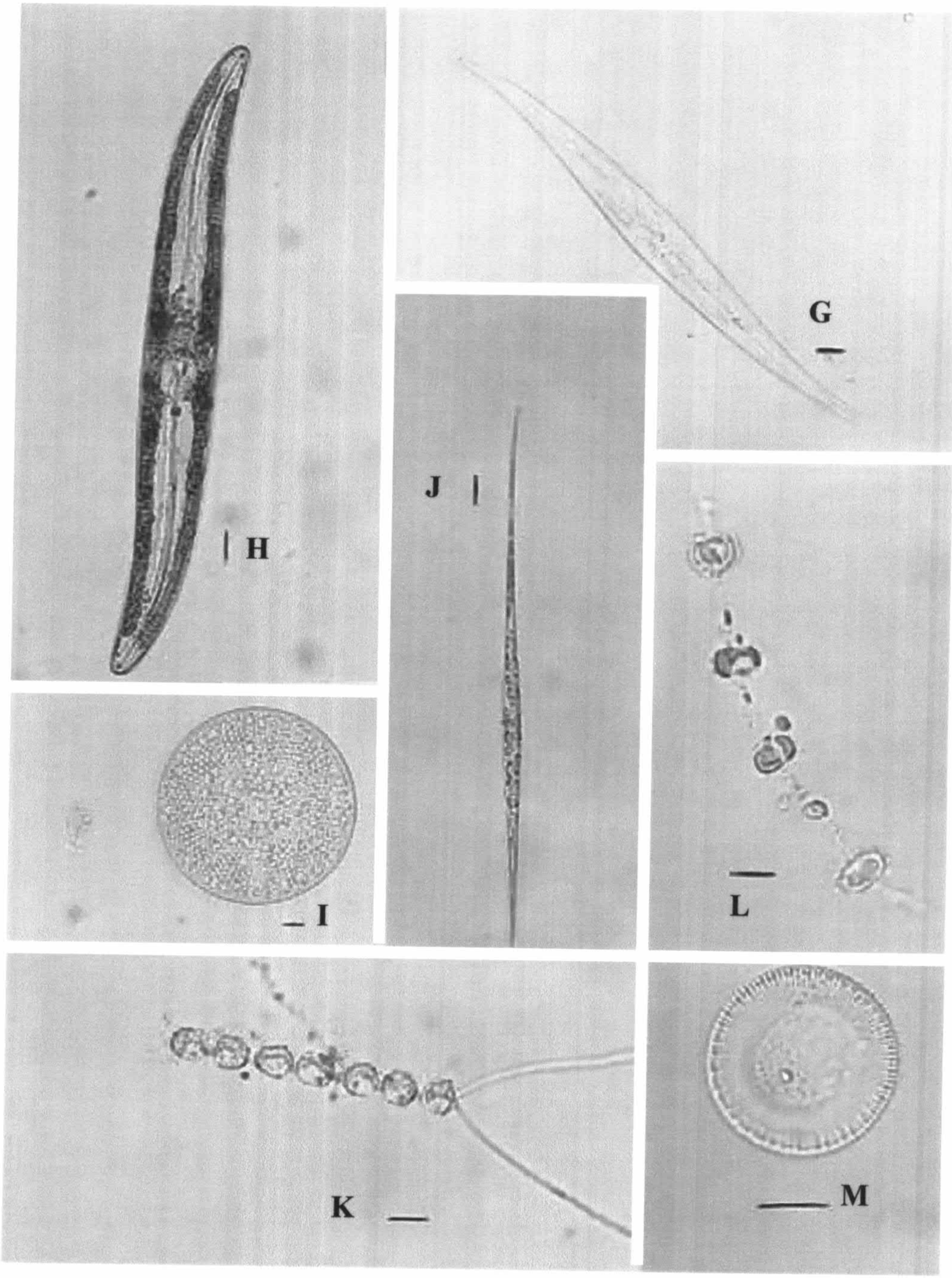


Figure 4.52 (Cont.) Dominant phytoplankton species in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed, *Oscillatoria* sp. (A), *Tabellaria* sp. (B), *Navicula* sp. (C), *Nitzschia* sp. (D), *Surirella* sp.(E), *Microcystis* sp.(F), *Gyrosigma* sp.(G), *Pleurosigma* sp. (H), *Coscinodiscus* sp. (I), *Rhizosolenia* sp. (J), *Chaetoceros* sp. (K), *Skeletonema* sp. (L) and *Cyclotella* sp. (M), scale bar — = 10 micron

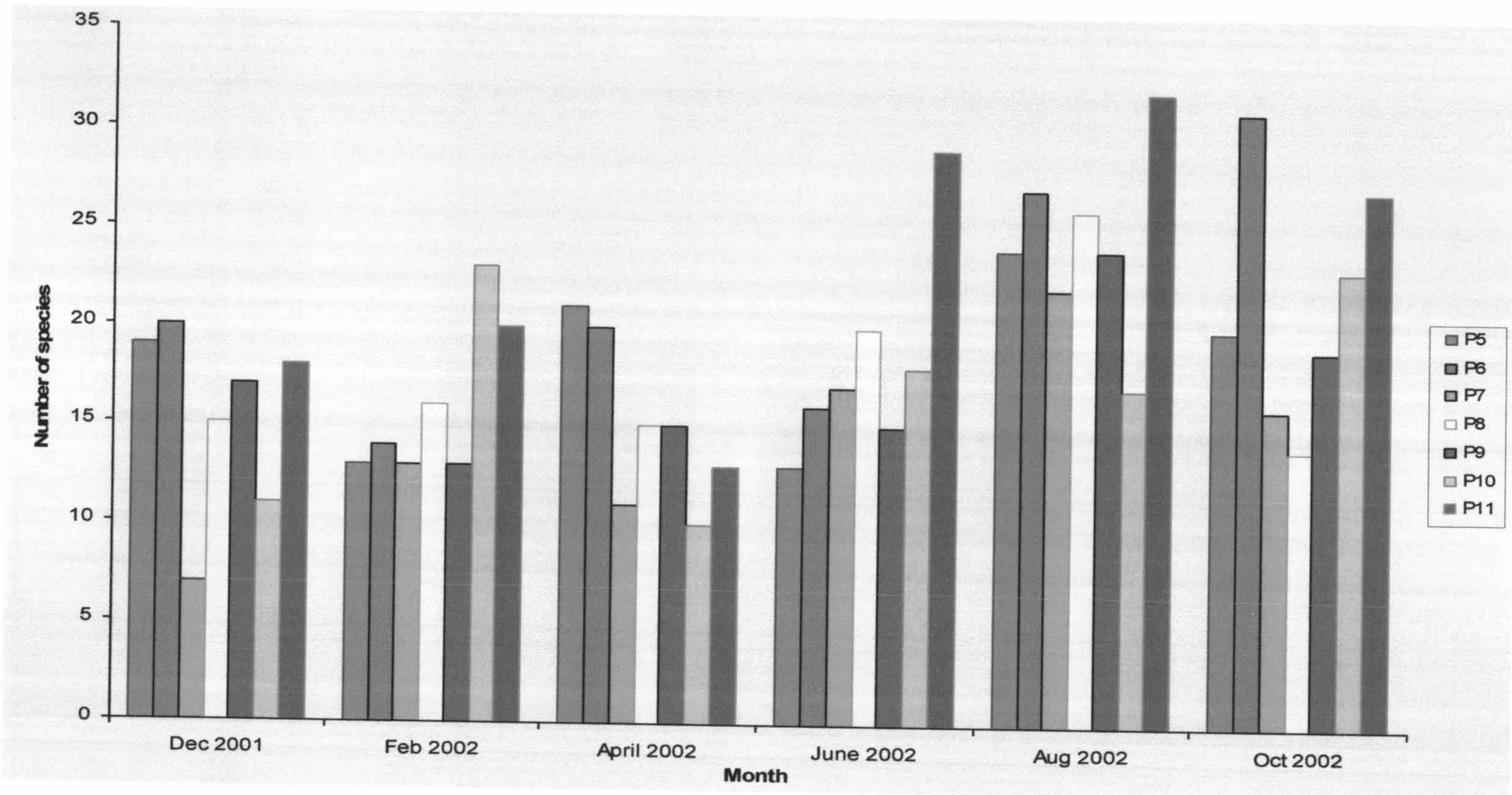


Figure 4.53 Number of species composition of subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary

4.5.3.3 Phytoplankton Density in Subsystem III (Downstream from Kaeng Krachan Reservoir to the River Mouths) of Phetchaburi Watershed

Table 4.11 shows the total density of phytoplankton in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) that consisted of seven stations. Phytoplankton density at all five inland stations (stations P5 to P9) were lower than phytoplankton density at the river mouth stations (stations P10 and P11). It was found that phytoplankton densities in the wet season of all stations were higher than in the dry season (Figure 4.54 A-G). This result was contrasted to the up stream area at the upstream is disturbed by a high flow of water in the wet season. While as all downstream stations have affected from the regulated water system of the Kaeng Krachan Reservoir and Phetchaburi Dam. Then the velocity in downstream was slower than in upstream. In addition, high nutrients flowed into the water bodies in the wet season. These conditions were suitable for phytoplankton growth, especially at station P5 (Downstream of Phetchaburi river from Kaeng Krachan Reservoir) had the phytoplankton groups liked in the Kaeng Krachan Reservoir. Cyanobacteria were the most abundance at all five inland stations throughout the year. Then the dominant changed at station P10 and P11. In the area of both river mouths, some bracklist diatoms grew, especially, at station P10 where there were phytoplankton blooms in the wet season. Diatoms are usually dominant of plankton in a large river along with, particularly in summer, a variety of green algae, many flagellates, cryophytes and cyanobacteria are vigorous; these groups can increase in areas where currents are reducing (Wetzel, 2001). This study found that cyanobacteria especially *Oscillatoria* spp.were dominant throughout the year of inland stations at the downstream except at station P5. *Microcystis aeruginosa* were dominant at this station that were the same dominant species in Kaeng Krachan Reservoir. In addition, cyanobacteria were the second dominant group at the Phetchaburi and Bang Taboon River Mouths. In the river mouth areas phytoplankton density had highly positive correlated with nutrient concentrations Then the wastewater treatment of aquacutural farms in these areas must be controlled in order to reduce nutrient loading the into the water bodies.

Table 4.11 Phytoplankton density in subsystem III

Month	Station	Phytoplankton density(unit/m3) x 10^6
Dec-01	P5	5634.67 ± 301.35
	P6	3880 ± 185.93
	P7	1087.68 ± 98.03
	P8	1098.67 ± 58.19
	P9	2693.33 ± 124.04
	P10	1089.14 ± 49.28
	P11	979.67 ± 46.5
Feb-02	P5	239.33 ± 9.49
	P6	1241.67 ± 90.43
	P7	1044 ± 75.21
	P8	2274 ± 104.39
	P9	1664 ± 85.23
	P10	16896 ± 743.34
	P11	4184.33 ± 261.69
Apr-02	P5	20183.33 ± 1587.78
	P6	5303.33 ± 418.31
	P7	276.34 ± 16.87
	P8	4670 ± 235.29
	P9	11283.33 ± 520.84
	P10	1043.33 ± 80.96
	P11	2263.33 ± 167.17
Jun-02	P5	34756.67 ± 2903.06
	P6	8450 ± 737.44
	P7	50156.67 ± 4750.87
	P8	8148.33 ± 501.09
	P9	7760 ± 395.81
	P10	441801.67 ± 29240.77
	P11	85250.56 ± 6228.27
Aug-02	P5	34608 ± 2451.82
	P6	167386 ± 11946.37
	P7	26652 ± 1646.23
	P8	27890 ± 1699.36
	P9	21278 ± 1409.92
	P10	100094 ± 7165.23
	P11	25396 ± 2328.3
Oct-02	P5	24617.5 ± 1930.7
	P6	6575 ± 409.81
	P7	4522.5 ± 264.86
	P8	877.5 ± 43.71
	P9	4400 ± 268.03
	P10	573205 ± 53752.33
	P11	149640 ± 9125.35

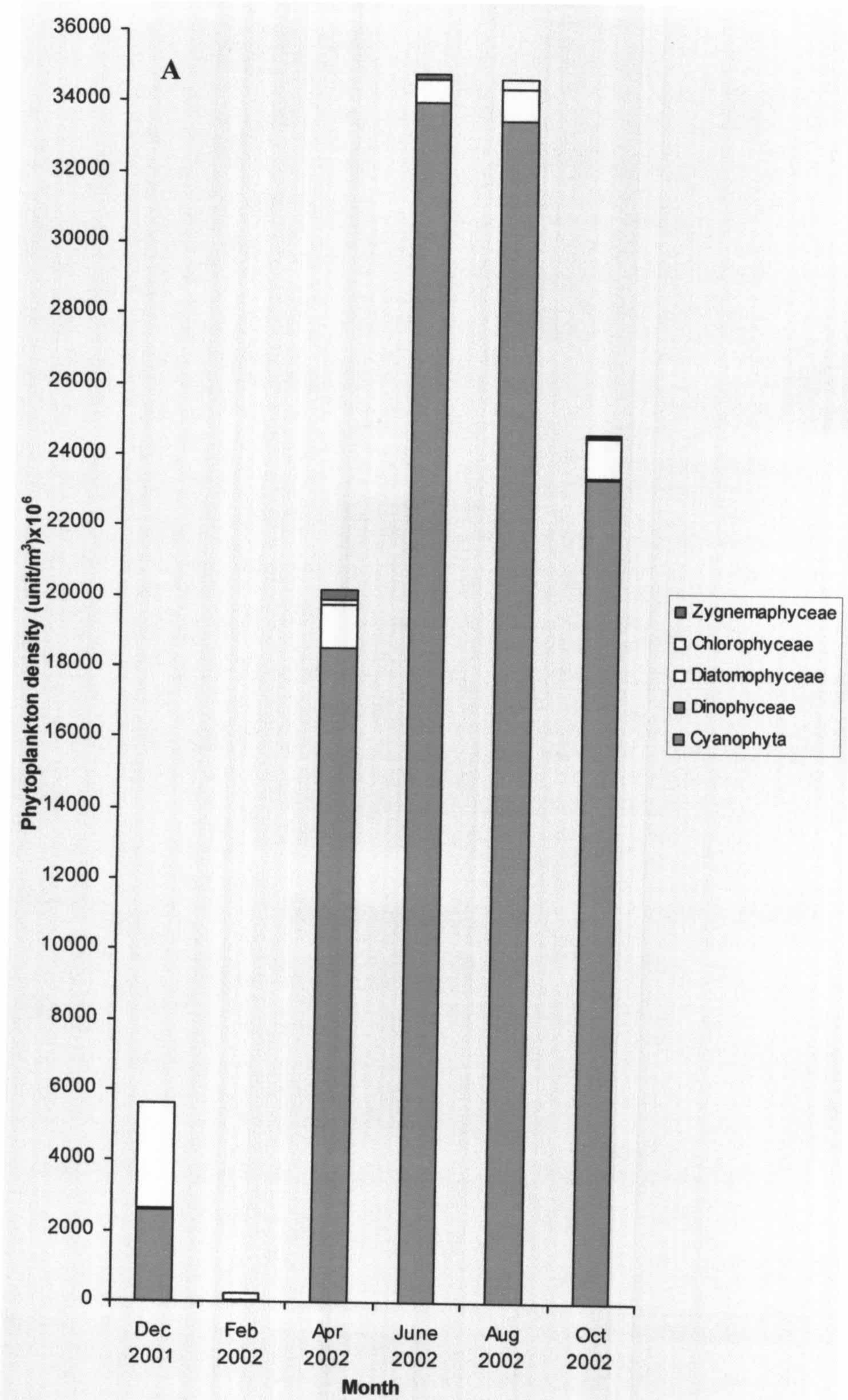


Figure 4.54 Seasonal variation of phytoplankton density (unit/m^3)x10^6 and portion of the taxonomic groups in station P5 (A), station P6 (B), station P7 (C), station P8 (D), station P9 (E), station P10 (F) and station P11 (G)

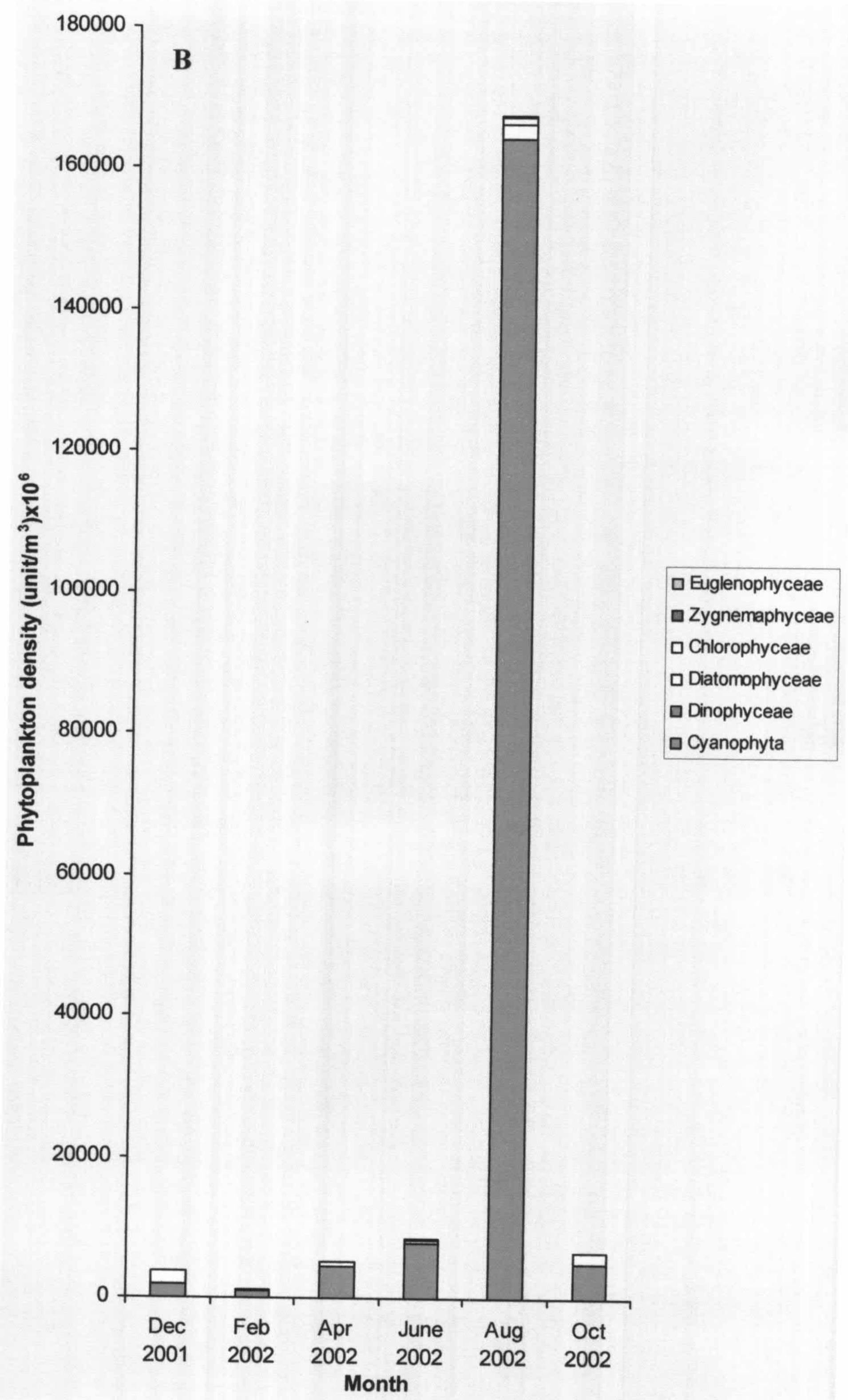


Figure 4.54 (Cont.) Seasonal variation of phytoplankton density (unit/m^3)x10^6 and portion of the taxonomic groups in station P5 (A), station P6 (B), station P7 (C), station P8 (D), station P9 (E), station P10 (F) and station P11 (G)

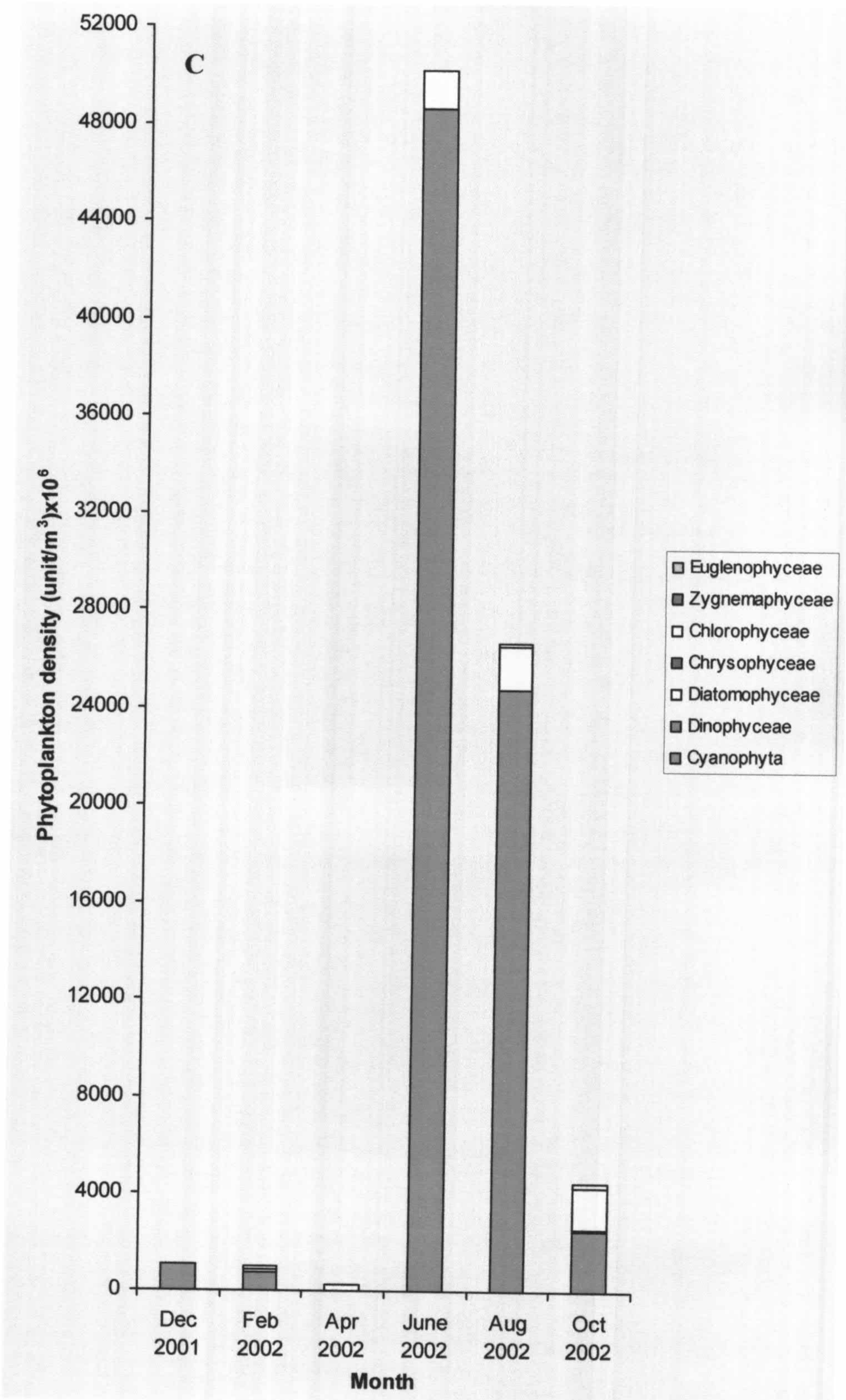


Figure 4.54 (Cont.) Seasonal variation of phytoplankton density (unit/m^3)x10^6 and portion of the taxonomic groups in station P5 (A), station P6 (B), station P7 (C), station P8 (D), station P9 (E), station P10 (F) and station P11 (G)

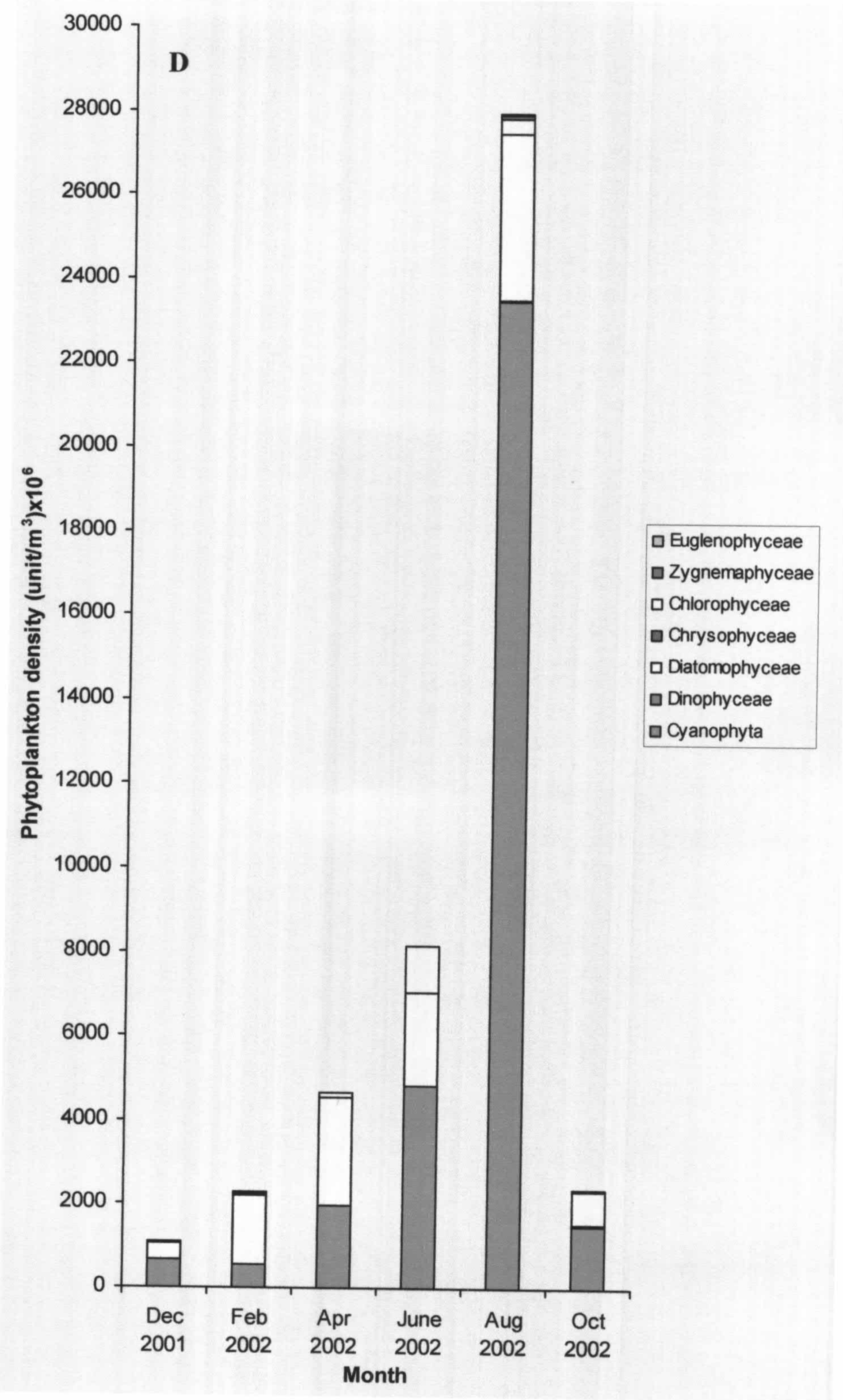


Figure 4.54 (Cont.) Seasonal variation of phytoplankton density (unit/m^3)x10^6 and portion of the taxonomic groups in station P5 (A), station P6 (B), station P7 (C), station P8 (D), station P9 (E), station P10 (F) and station P11 (G)

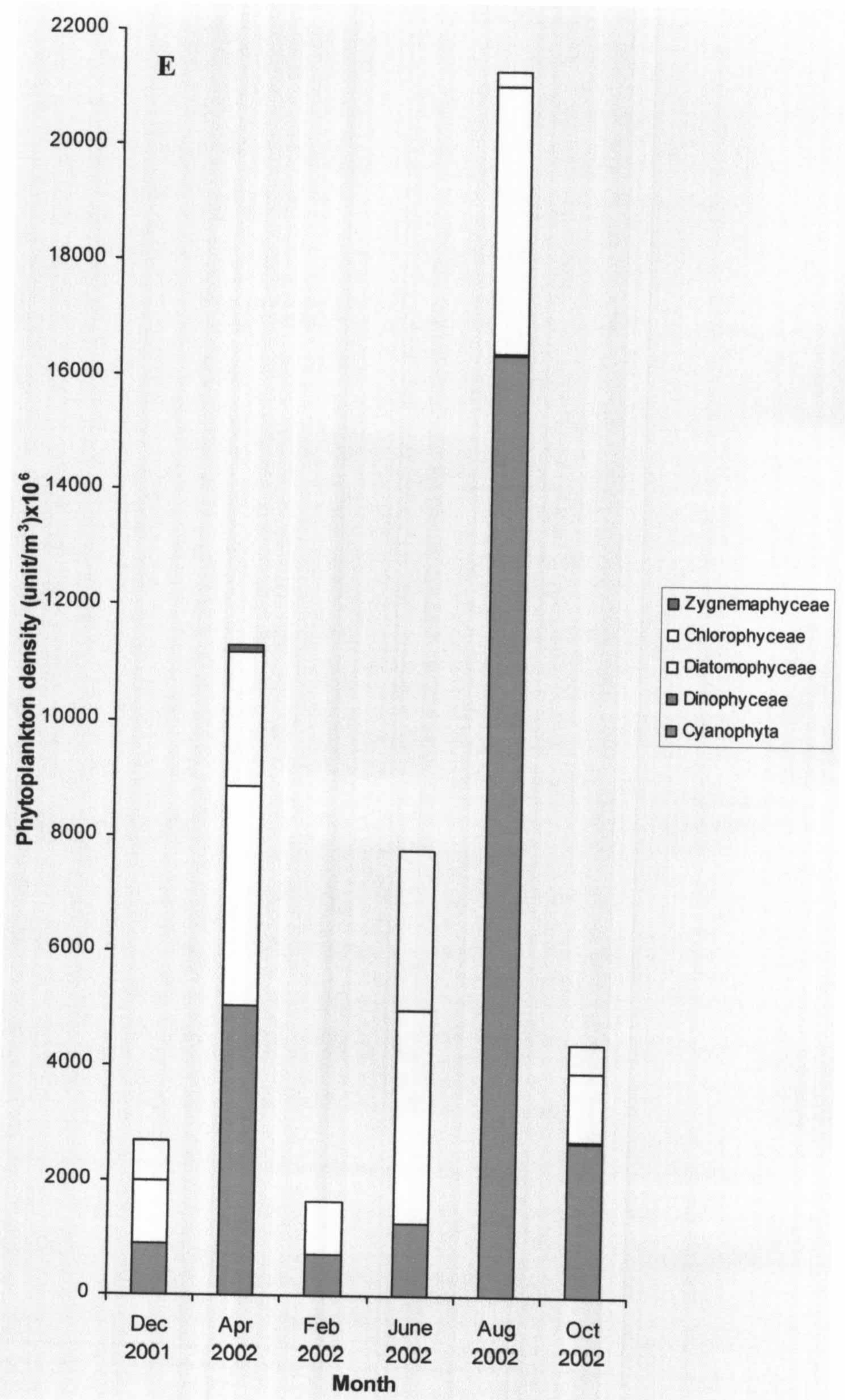


Figure 4.54 (Cont.) Seasonal variation of phytoplankton density (unit/m^3)x10^6 and portion of the taxonomic groups in station P5 (A), station P6 (B), station P7 (C), station P8 (D), station P9 (E), station P10 (F) and station P11 (G)

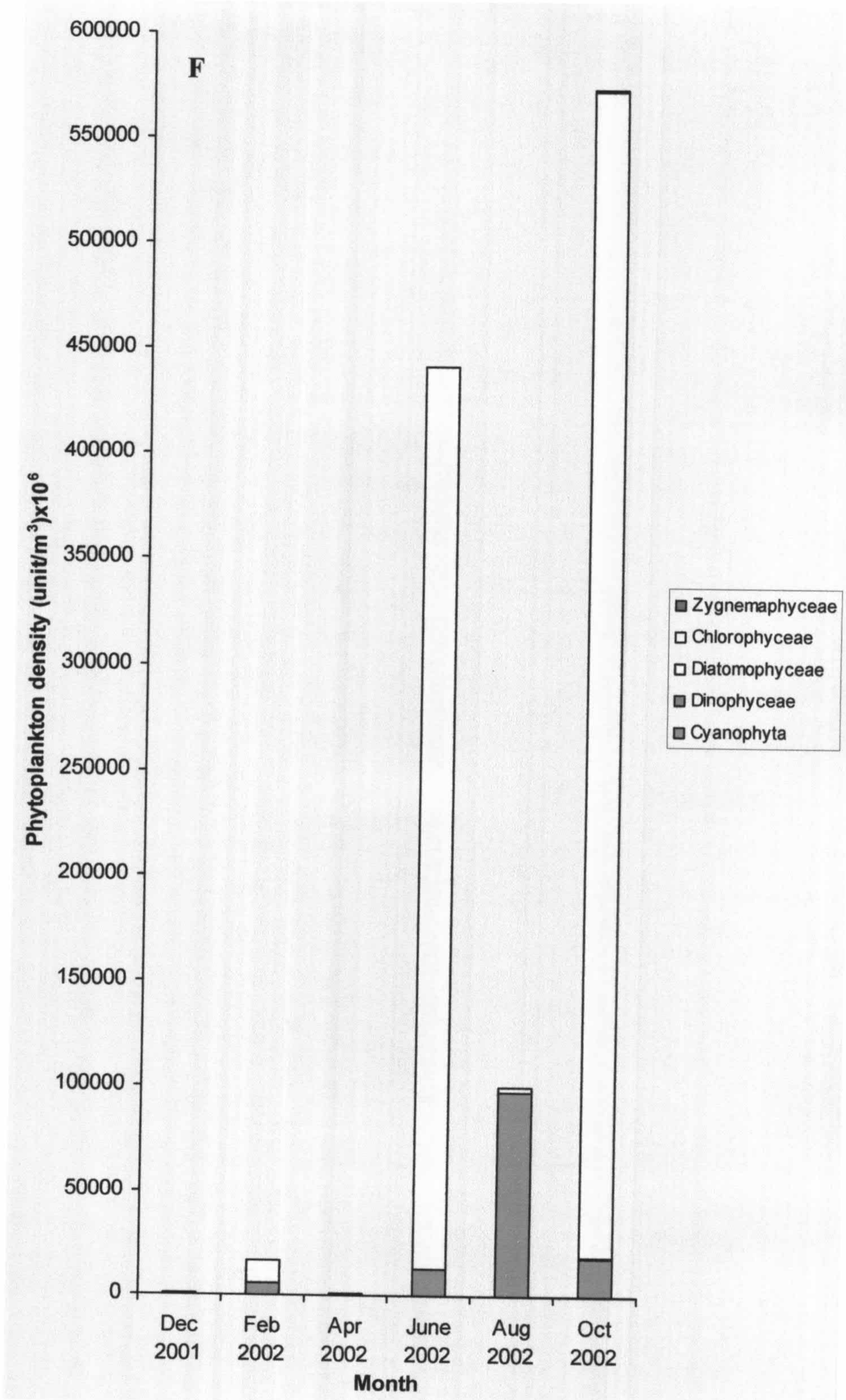


Figure 4.54 (Cont.) Seasonal variation of phytoplankton density (unit/m^3)x10^6 and portion of the taxonomic groups in station P5 (A), station P6 (B), station P7 (C), station P8 (D), station P9 (E), station P10 (F) and station P11 (G)

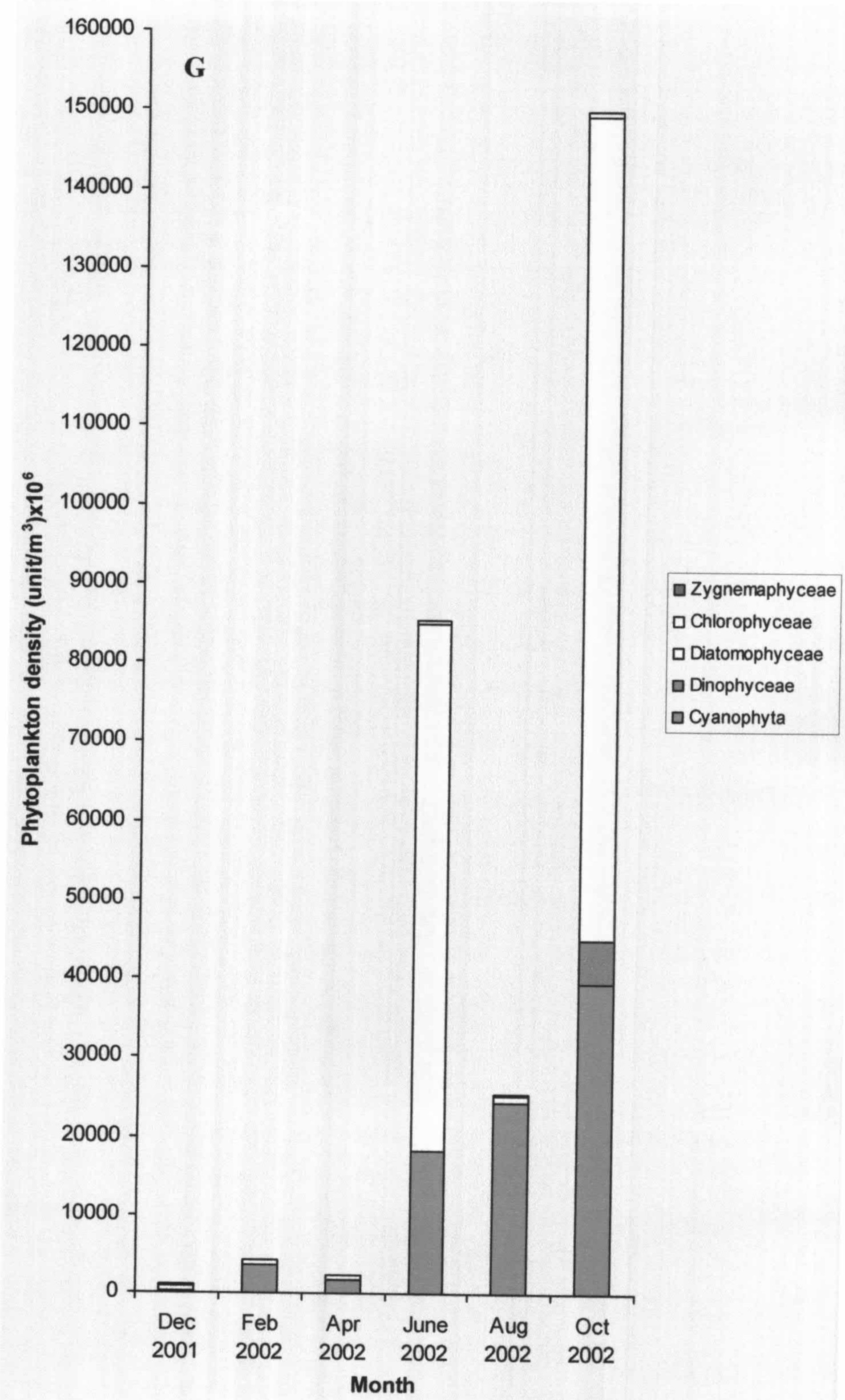


Figure 4.54 (Cont.) Seasonal variation of phytoplankton density (unit/m^3)x10^6 and portion of the taxonomic groups in station P5 (A), station P6 (B), station P7 (C), station P8 (D), station P9 (E), station P10 (F) and station P11 (G)

4.5.3.4 Chlorophyll *a*

The averages of chlorophyll *a* concentration ranged from 0.35 ± 0.00 to 112.81 ± 6.18 mg/m^3. The highest average of chlorophyll *a* concentration was 112.81 ± 6.18 mg/m^3 at station P10 at the end of the wet season (October 2002) and the lowest was 0.35 ± 0.00 mg/m^3 at the station P8 in the middle of the dry season (February 2002) (Figure 4.55).

Chlorophyll *a* concentration at all five inland stations (stations P5 to P9) were lower than chlorophyll *a* concentration at the river mouth stations (stations P10 and P11). This study corresponds to Pollution Control Department (2002) Furthermore, there were some reports that chlorophyll *a* concentration was decreased gradually toward river mouth such as, in the Khumpuan Estuary, Ranong Province (Tanyaros, 1993), in the Bangpakong River (Hourban, 1997) and in the Chao Phraya river (Pradissan, 2000). This study also found that chlorophyll *a* concentration of all inland stations in the dry season was higher than in the wet season. This affected from the high turbid of the waterflow especially the high flood to the river mouths in August 2002. Then at the river mouth areas, chlorophyll *a* concentration was highly increased throughout the investigation especially in the wet season. These areas have received numerous nutrients from the waterflow in the wet season. In addition, both river mouths had phytoplankton blooms.

From this study, it was found that the areas of Phetchaburi and Bang Taboon River Mouths had enriched nutrients and high chlorophyll *a* concentration when they were compared with other researchers. They reported that chlorophyll *a* concentration in Bangpakong River, Tha Chin River Mouth, Chao Phraya River ranged from ND-84.99 mg/m^3, 7.85 - 38.14 $mg/m^3$and 0.59 - 342.04 mg/m^3, respectively (Hourban, 1997; Promthong,1999; Pradissan, 2000). However, the Chao Phraya River was very high chlorophyll *a* concentration.

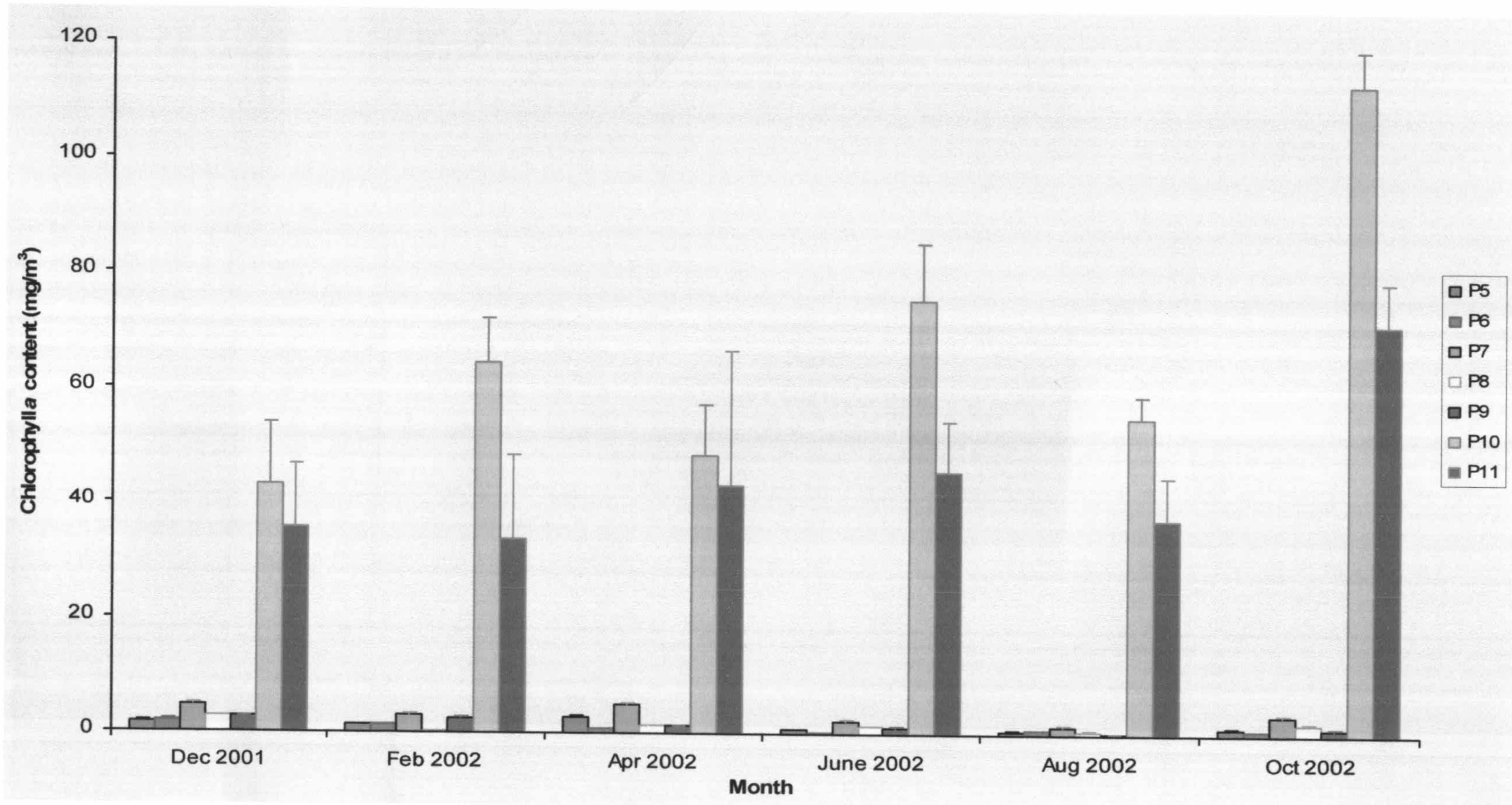


Figure 4.55 Average of chlorophyll *a* in subsystem III (downstream from the Reservoir to the river mouths) of Phetchaburi Watershed

Note: P5 = downstream of Phetchaburi River from Kaeng Krachan Reservoir, P6 = Huai Pak Subwatershed, P7 = Mae Prachan Subwatershed, P8 = agricultural area at downstream, Phetchaburi River, P9 = domestic and industrial areas, Amphoe Maung, Phetchaburi Province, P10 = aquaculture area at Ban Laem Estuary, P11 = aquaculture area at Bang Taboon Estuary

4.5.3.5 Shannon-Wiener's Index of phytoplankton in subsystem III (downstream)

Shannon-Wiener's Index of phytoplankton of seven stations in subsystem III had tended to be correlated to the seasons (Table 4.12). Shannon-Wiener's Index ranged from 0.355 to 2.18. The Shannon-Wiener's index at all stations in the dry season was higher than in the wet season. Although the numbers of species in the dry season were lower than in the wet season, smaller numbers of density were the reason for the high values of the Shannon-Wiener's Index. Polution Control Department (2002) reported that the phytoplankton diversity index in the Phetchaburi River ranged from 0.992 to 2.072. It was found that the lowest value was at the area of upstream and the highest value was at the area of the Phetchaburi River Mouth. Contrasting to this study found that the value of the diversity index were higher than at the river mouths, especially Phetchaburi River Mouth. In addition, the value of the index at the river mouths in the dry season was higher than in the wet season because of the blooming of diatom and blue-green algae in the wet season. Besides, the Shannon-Wiener's Index in the agricultural and domestic areas at downstream of the watershed was higher than in other areas (station P5, P6, P7, P10 and P11). This study was similar to the study of the phytoplankton diversity in Lam Phra Phloeng Watershed. Noinumsai (2000) reported that the average of the phytoplankton Shannon-Wiener's Index in the agricultural area of Lam Phra Phloeng Watershed was higher than at the head water. This study found that the average value of the diversity index in head water area was higher than in downstream areas, especially in the wet season.

Table 4.12 Shannon-Wiener's Index of phytoplankton in subsystem III (downstream) of Phetchaburi Watershed

Shannon-Wiener's Index							
Station	Dec-01	Feb-02	Apr-02	Jun-02	Aug-02	Oct-02	Annual year
P5	1.587	2.18	0.924	0.628	0.887	0.812	1.170
P6	1.775	1.153	1.024	0.637	0.831	1.445	1.144
P7	0.523	1.157	1.564	0.325	1.297	1.583	1.075
P8	1.731	1.769	1.629	1.506	1.474	1.846	1.659
P9	1.863	1.642	1.804	1.584	1.433	1.583	1.652
P10	1.897	1.986	0.946	1.069	0.811	0.355	1.177
P11	1.992	1.181	1.022	1.07	0.469	1.315	1.175

4.5.4 The Correlation between Ecological Parameters in Subsystem III (Downstream from Kaeng Krachan Reservoir to the River Mouths) of Phetchaburi Watershed

According to the investigation in subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths), the seven stations had different correlation between ecological parameters. The main river flowed to the downstream, and then it passed through various areas that were varied in land use patterns such as; forest, agriculture, community, industry, aquaculture and including the recreation on the Phetchaburi River. These reasons affected ecological parameters and could change the relationships among them.

At station P5 (downstream of Phetchaburi River from Kaeng Krachan Reservoir), the phytoplankton density had a positive correlation to Phosphate-phosphorus and ammonium-nitrogen concentrations significantly at the p = 0.001 and 0.05, respectively (Table 18 in Appendix E). Chlorophyll *a* concentration had a negative correlation to most nutrients and phytoplankton density. Station P5 located under the outlet of the reservoir, then it had different in flow rate that affected to phytoplankton growth and its photosynthesis, especially in the rainy season. All nutrients had tended to correlate to suspended solid but not significantly. In addition, both of phytoplankton density and chlorophyll *a* concentration were significantly different within the seasons at the p = 0.05 (Table 5 in Appendix E). This study revealed that phytoplankton density and chlorophyll *a* concentration in the dry season were higher than in the wet season. This corresponds to Graham and Wilcox (2000) which states that the streamflow in the wet season can reduce the density of river phytoplankton.

At station P6 (Huai Pak Subwatershed), the phytoplankton density and chlorophyll *a* concentration had a positive correlation to nitrate-nitrogen concentration (Table 19 in Appendix E). However, chlorophyll *a* concentration had a negative correlation to Phosphate-phosphorus concentration significantly at the p = 0.0001. The correlation between phytoplankton density and nutrients at station P6 was the same as station P5. Although there were high nutrients, the water was very turbid (field notation) and transparency depth was low. In addition, the velocity was high in the wet season. This might decrease in phytoplankton density from the water surface, and then chlorophyll *a* concentration was low. However, phytoplankton density and chlorophyll *a* concentration at station P6 in the dry season was higher than in the wet season.

At station P7 (Mae Prachan Subwatershed), the phytoplankton density had a positive correlation to Phosphate-phosphorus and silica-silicon concentrations. However, phytoplankton had a negative correlation to chlorophyll *a* concentration significantly at the $p = 0.001$ (Table 20 in Appendix E). Station P7 was located at the downstream of Mae Prachan Subwatershed in which, the reservoir has been constructing at the head water areas and causing high suspended solid concentration. Suspended solid can cause transparency depth reduction. In addition, Chlorophyll *a* concentration had a positive correlation to transparency depth significantly at the $p = 0.05$. Besides, the water depth in this subwatershed was low throughout the year excepted when there was a rainfall. Most people in these areas are famers and need water for their farms (National Statistical Office, 2002). Besides, the soil characteristics in this area cannot store water (Land and Development, 2001). The suspended solid was considered to be the important problem in this subwatershed. Its concentration was higher than other stations that were located at the inland.

At station P8, the station was surrounding with agricultural area in the Phetchaburi River. The stream flow was lower than the above stations. Phytoplankton density was positively correlated with nitrate-nitrogen, nitrite-nitrogen and ammonium-nitrogen concentrations significantly at the $p = 0.0001$, 0.005 and 0.01, respectively (Table 21 in Appendix E). However, chlorophyll *a* concentration had a negative correlation to phytoplankton biovolume significantly at the $p = 0.05$. The density of diatom had tended to increase at this area. Diatoms have higher contents of carotenoid and xanthophyll pigments than chlorophyll *a* so the phytoplankton biovolume did not correlate to chlorophyll *a* concentration in this station.

At station P9, this station was located at Phetchaburi municipality. The station was set about 500 m of the distance under the drainage pipes of wastewater that take water from the river to the water treatment system. Then the nutrients in the water were decreased before flew to the station P9. Phytoplankton density there had a positive correlation to nitrate-nitrogen and ammonium-nitrogen significantly at the $p = 0.001$ and 0.0001, respectively (Table 22 in Appendix E). The chlorophyll *a* concentration and phytoplankton density were negatively correlated, it was the same as at the station P8. Phytoplankton density had tended to negatively correlate with suspended solid and transparency depth.

At station P10 and P11, these are the two outlets of the Phetchaburi watersheds. Station P10 was located at the Phetchaburi River Mouth and station P11 was located at the Bang Taboon River Mouth. Both stations had higher phytoplankton densities and chlorophyll *a* concentrations than other stations upstream because because of the difference in lant use patterns (Table 4.1, Figure 4.7). The areas surrounding station P10 and P11 are a plenty of aquacultural farms. Thus they discharge high nutrient loading into the rivers (Pollution Control Department, 2001).

At station P10, several fisherman villages live along the river mouth which discharge wastewater directly into the river. According to the correlation analysis, phytoplankton density had a positive correlation to chlorophyll *a* concentration significantly at the p = 0.0001 (Table 23 in Appendix E), especially during phytoplankton blooms in June and October in the year 2002. The study found that, phytoplankton density had a negative correlation to nitrate-nitrogen , nitrite-nitrogen, Phosphate-phosphorus and silica-silicon concentrations significantly at the p = 0.0001, 0.001, 0.005 and 0.05, respectively. Besides, chlorophyll *a* concentration also had a negative correlation with nitrate-nitrogen , nitrite-nitrogen and concentrations significantly at the p = 0.0001. In contrast, both of phytoplankton density and chlorophyll *a* concentration had a positive correlation to ammonia – nitrogen concentration significantly at the p = 0.0001. These might be affecting phytoplankton bloom. In the period of the bloom, the rates of nutrient uptakes are high. These can decrease some nutrient concentrations from the water, especially silica-silicon concentration that was highly decreased in the blooming periods. Silicon is very important nutrient for diatoms that can assimilate large quantities of silicon in the synthesis of their frustules (Wetzel, 2001 and Graham and Wilcox, 2000). This study found that diatoms were at the highest density in station P10 in several times of blooms throughout the year. Phytoplankton density and chlorophyll *a* concentration also had a positive correlation with pH value. When phytoplankton bloom occurs, the pH value slightly increases (Wetzel, 2001).

At station P11, the Bang Taboon River Mouth is wider than Phetchaburi River Mouth (Station P10). Then water volume at station P11 was also more than at station P10. Considering their correlations was slightly different. The Phytoplankton density at station P11 had a positive correlation to chlorophyll *a* concentration significantly at the p = 0.0001 (Table 24 in Appendix E). Both of them had a positive correlation to ammonium-nitrogen concentration significantly at the p = 0.0001. Phytoplankton density had a negative correlation to nitrate-nitrogen , nitrite-nitrogen and silica-silicon concentration significantly at the p = 0.01, 0.0001 and 0.001, respectively.

Focusing on to the two river mouths, although there were phytoplankton blooms were found at Bang Taboon River Mouth, while the phytoplankton density and chlorophyll *a* concentration at Phetchaburi River Mouth were higher than at Bang Taboon River Mouth. It seemed that these areas were nutrient enrichments. In addition, all nutrient concentrations had tent to correlate to the rate of rainfall that was high in the study period.

Table 4.13 shows the comparison of some physico-chemical parameters; transparency depth, salinity, phosphate-phosphorus and nitrate-nitrogen concentrations, chlorophyll *a* concentration and biological characteristics; number of genera and dominant groups of phytoplankton among the river and river mouth ecosystems at Thai waters and other tropical regions. The studies of Thai waters mentioned here are Chai River, Maeklong River, Bangpakong River, Mae Sa River, Phetchaburi River, Lam Pha Phloeng River, Tha Chin River and Chao Praya River. For the previous studies of river mouths, the characteristics of interest of Meklong river mouth, Tha chin river mouth, Klong-Sikao River Mouth, Phetchaburi and Bangtaboon River Mouths (present study) and Strait Johor waters of Singapore are addressed. It was found that physico-chemical and biological characteristics in the river were higher than those in the river mouth area. When compare above characters among the eight river waters, they are mostly found in high values, especially the river in the central part such as Maeklong River, Bangpakong River, Tha Chin River and Chao Praya River. The range of transparency depth, salinity, phosphate-phosphorus and nitrate-nitrogen concentrations, chlorophyll *a* concentration and number of genera is 0.05 - 69.85 meters, 0 - 29 ppt, ND - 653 ug/l, ND - 1490 ug/l ND - 342 ug/l and 31 - 116 genera

Table 4.13 Comparison of some physico-chemical and biological characteristics (annual averages) and dominant groups in river and river mouth ecosystems in the tropical region (ND = could not be detected, NA = not available)

Country or Region	Western Thailand	North – Eastern Thailand	Western Thailand	Eastern Thailand	Northern Thailand
	Present study	Koelek 1989	Rakkittham 1996	Horaban 1997	Peerapornpisal et al. 2000
Name of water resource	**Watershed Phetchaburi**	**River Chai**	**River Mae Klong**	**River Bangpakong**	**River Mae Sa**
Secchi depth (m)	0.20 – 2.80	1.22	14.00 – 69.85	0.05 – 1.10	0.84
Salinity	0-24.	NA	NA	0.1 29.0	NA
Phosphate-Phosphorus	ND – 132.52	NA	240.00 – 640.00	ND – 653.00	NA
Nitrate-nitrogen (ug/l)	ND – 199.20	872.08	NA	ND-1,190.00	149.45
Chlorophyll *a* (ug/l)	0.35 – 123.06	NA	NA	ND – 84.99	NA
Number of genera	52	41	60	116	31
Phytoplankton groups or species	Cyano. : *Oscillatoria* *M. aeruginosa* Diatom. : *Navicular - Surirella*	Diatom. : *Fragilaria* sp.	Cyano. : *Oscillatoria* Diatom. : *Surirella* *Molesira*	Diatom. : *Cossinodiscus* *Odontella* *Navicular* Cyano. : *Oscillatoria*	Diatom. : *Melosira varians* *Fragilaria ulna* *Cymbella tumida* *Nitzchia lineris*

Table 4.13 (Cont.) Comparison of some physico-chemical and biological characteristics (annual averages) and dominant groups in river and river mouth ecosystems in the tropical region (ND = could not be detected, NA = not available)

Country or Region	North-Eastern Thailand Noinamsai 2000	Central Thailand Chaleoisak 2000	Central Thailand Pradissan 2002	Western Thailand Present study	Southern Thailand Ganbua 1998
Name of water resource	**Watershed Lam Pha Phloeng**	**River Tha Chin**	**River Chao Praya**	**River mouth Phetchaburi**	**River Klong Si Koa**
Secchi depth (m)	0.58 ± 0.40	0.40 – 1.30	0.10 – 1.20	0.20 – 0.60	0.64 – 1.30
Salinity	NA	NA	0 - 20	1 – 24	19.67 - 28.99
Phosphate-Phosphorus	235.50 ± 200.00	NA	20.00 – 570.00	18.79 – 128.20	33.00 - 360.00
Nitrate-nitrogen (ug/l)	212.00 ± 10.00	ND – 1346.00	ND – 1490.00	5.74 – 199.20	4.00 - 49.00
Chlorophyll *a* (ug/l)	NA	NA	0.59 – 342.04	30.21 – 123.06	2.25 – 6.38
Number of genera	47	NA	130	41	62
Phytoplankton groups or species	Diatom. : *Fragilaria* sp.	Cyano. : *Oscillatoria sp.* *Spirulina platensis*	Diatom. : *Melosila granulata*	Diatom. : *Cossinodiscus* *Chaetoceros* *Skeletonema* *Rhizosolenia* Cyano. : *Oscillatoria*	Diatom. : *Guinardia* *Rhizosolenia* Cyano. : *Anabaena* *Oscillatoria*

Table 4.13 (Cont.) Comparison of some physico-chemical and biological characteristics (annual averages) and dominant groups in river and river mouth ecosystems in the tropical region (ND = could not be detected, NA = not available)

Country or Region	Western Thailand Present study	Western Thailand Present study	Western Thailand Buatong 1997	Central Thailand Phromthong 1999	Singapore Gin et al. 2000
Name of water resource	**River mouth Phetchaburi**	**River mouth Bang Taboon**	**River mouth Mae Klong**	**River mouth Tha Chin**	**Strait Johor (many river mouths)**
Secchi depth (m)	0.20 – 0.60	0.25 – 0.75	0.50 – 1.15	1.13 – 6.63	NA
Salinity	1 – 24	8 – 23	2.32 – 22.42	5.01 – 19.17	19 – 33
Phosphate-Phosphorus	18.79 – 128.20	27.33 – 132.52	NA	402.80 – 1444.00	7.00 – 75.00
Nitrate-nitrogen (ug/l)	5.74 – 199.20	ND – 157.05	NA	5.58 – 422.84	13.00 – 400.00
Chlorophyll *a* (ug/l)	30.21 – 123.06	12.25 – 82.24	NA	7.85 – 38.14	1.00 – 78.50
Number of genera	41	43	80	70	NA
Phytoplankton groups or species	Diatom. : *Cossinodiscus* *Chaetoceros* *Skeletonema* *Rhizosolenia* Cyano. : *Oscillatoria*	Diatom. : *Cossinodiscus* *Chaetoceros* *Skeletonema* *Rhizosolenia* Cyano. : *Oscillatoria*	Diatom. : *Chaetoceros* *Nitzschia* *Rhizosolenia*	Diatom. : *Skeletonema* sp. *Thalassiosira* sp. *Nitzchia* sp. Cyano. : *Anabaena* *Oscillatoria*	Diatom. : *Chaetoceros* *Skeletonema*

by respectively. The data showed that most of characters in Thai waters is higher than those in Singapore water except salinity. When compare the characters within Thai River Mouths, it showed the range of transparency between 0.2 - 6.63 meters, 1 - 33 for salinity, 4.24 - 132.52 ug/l and ND - 776 for phosphate-phosphorus and nitrate-nitrogen concentration, 1 - 123.06 ug/l for chlorophyll concentration and 41 - 80 of phytoplankton genera number. Furthermore, this study showed that there were differences between this study and other areas in phosphate-phosphorus concentration, nitrate concentration, chlorophyll *a* concentration and number of genera. This study showed higher values on of phosphate and chlorophyll *a* concentration and lower values on nitrate concentration and number of genera of phytoplankton. Diatom is the most dominant group in this study which corresponds to other studies.

From the study, the water quality of almost all stations in the subsystem III were in the range of the standard of surface water quality in Thailand (Pollution Control Department, 1997) that were classified as the second to third category (Table 4.17), except in Phetchaburi River Mouth. Its dissolved oxygen was very low in the dry season. All nutrient concentrations had tended to correlate within the seasons and rainfal. However, it must be concern that the suspended solid at Mae Prachan Subwatershed was high throughout the year. It must be concern that the nutrient enrichments at Phetchaburi and Bang Taboon River Mouths. Then phytoplankton could bloom in the areas of river mouths.

4.6 Comparison of Land Uses and some Ecological Parameters in Four Subwatersheds on the Phetchaburi Watershed

To study the effect of land use patterns on nutrient loading, this topic compared percentage of each type of land use areas. Based on the watershed boundary, the four small subwatersheds were divided by their topography lines (Figure 4.56).

The first subwatershed, Phet-Bang Kloy was located at the upstream (subsystem I) of the Phetchaburi Watershed (Figure 4.56). It covered the area of 976.46 sq.km. (Figure 4.57; Table 4.14) and its slope varied from 15 to 35 percent (Royal Thai Survey Department, 1991). All of the areas were in Kaeng Krachan National Park. The majority of area 99.74 percent (973.94 sq.km.) was forest and the rest was waterbody at 0.26 percent (2.52 sq.km.).

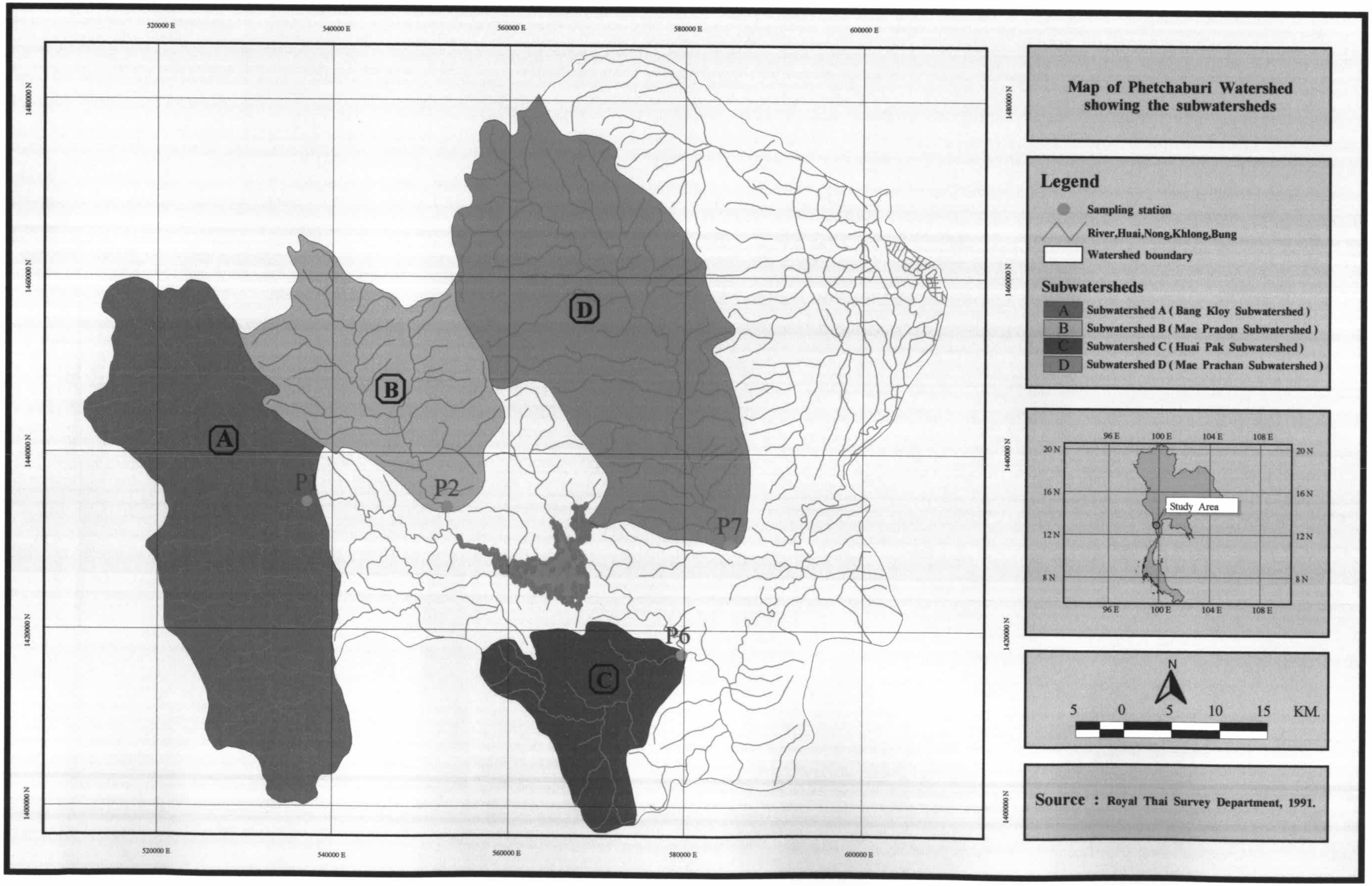


Figure 4.56 Lacation of the Subwatershed

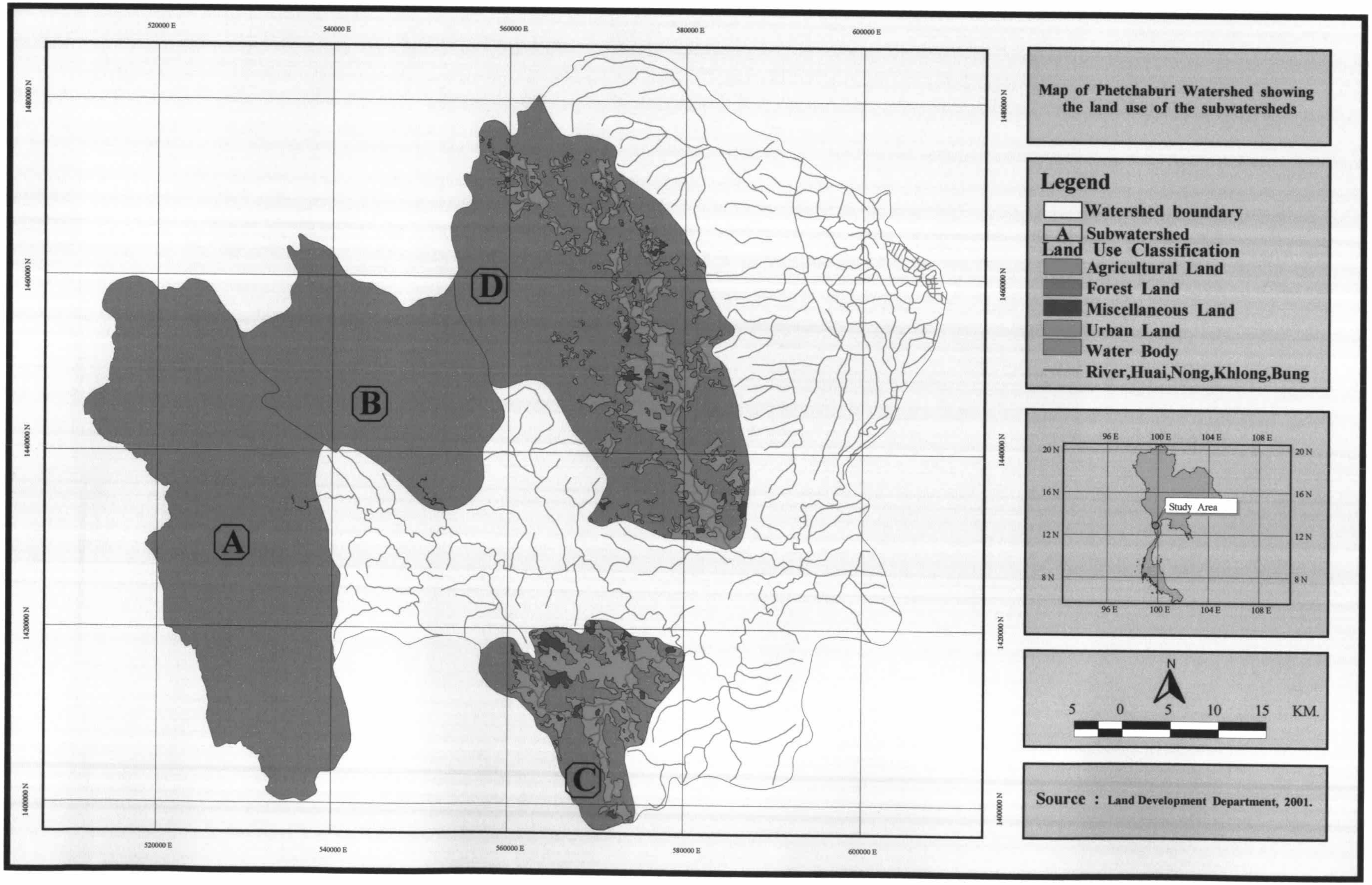


Figure 4.57 Land Use Map of the Subwatershed

Mae Pradon is the second subwatershed, located at the upstream (subsystem I) of the Phetchaburi Watershed. This subwatershed was smaller and less steeper slope than Phet-Bang Kloy Subwatershed. Mae Pradon Subwatershed covered the area of 521.06 sq.km. and its slope varied from 10 to 25 percent. All of the areas were in Kaeng Krachan National Park. The 99.88 percent (520.414 sq.km.) was forest areas and the rest was waterbody at 0.22 percent (0.650 sq.km.) (Table 4.14; Figure 4.58). However, the survey data of statistic of Phetchaburi Province (2002) reported that there were agricultural areas along the river banks of the Mae Pradon River. The field trips of the study period also found mix – orchards in this subwatershed.

Table 4.14 Land use classification of four subwatersheds

Land use classification	Area (sq.km.)			
	Phet-Bang Kloy Subwatershed	**Mae Pradon Subwatershed**	**Huai Pak Subwatershed**	**Mae Prachan Subwatershed**
Forest areas	973.936	520.414	166.691	749.138
Waterbody	2.524	0.650	1.485	5.750
Agricultural areas	-	-	110.572	211.177
Miscellaneous areas	-	-	14.444	9.439
Urban and built-up areas	-	-	1.391	3.668
Total	976.461	521.064	294.585	979.17

The third subwatershed, Huai Pak was located at the downstream (subsystem III) of Phetchaburi Watershed. It was the smallest subwatershed with small mountains. It covered the area of 294.59 sq.km. and its slope varied from 5 to 15 percent. The downstream areas were suitable for human settlement so this subwatershed had different land use patterns from the upstream areas. The land uses in this subwatershed consisted of forest areas (56.59%), agricultural areas (37.53%), miscellaneous areas (4.90%), waterbody (0.50%) and urban and built-up areas (0.47%) (Figure 4.58).

The fourth subwatershed, Mae Prachan was located at the downstream (subsystem III) of Phetchaburi Watershed. It was the biggest subwatershed and covered the area of 979.17 sq.km. Its slope varied from 5 to 10 percent. This subwatershed had a big river and flat plain areas. Thus it was very suitable for human settlement and agriculture. The land uses in this subwatershed consisted of forest areas (76.51%), agricultural areas (21.57%), miscellaneous areas (0.96%), urban and built-up land (0.59%) and waterbody (0.37%).

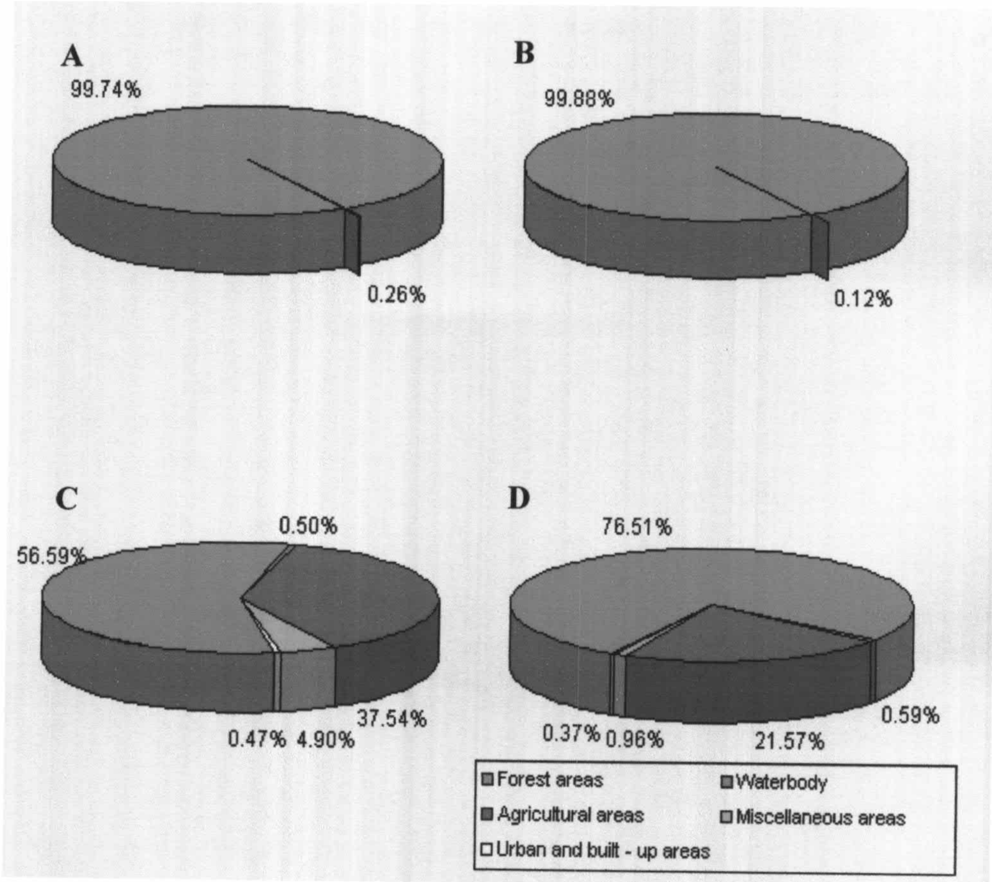


Figure 4.58 Percentages of land use patterns in four subwatersheds on Phetchaburi Watershed, Phet-Bang Kloy Subwatershed (A), Mae Pradon Subwatershed (B), Huai Pak Subwatershed (C) and Mae Prachan Subwatershed (D)

Comparison among the four subwatersheds, Phet-Bang Kloy and Mae Prachan Subwatersheds had high soil erosion then they were high suspended solids (Table 4.15). This affected to increase nutrient concentrations. However, Phet-Bang Kloy Subwatershed is at the head water and it has higher slope than other subwatersheds. While Mae Prachan Subwatershed is low slope, but has high agricultural areas. Then it seems that agriculture has tended to increase soil erosion rate. Besides, Mae Pradon Subwatershed has small agricultural areas along the river banks and its waterflow is usually slow (the field study and questionnaire). Then it was found that chlorophyll *a* concentration at downstream of Mae Pradon was very high when it was compare to other subwatersheds especially in the dry season. Furthermore, this subwatershed is in upstream above the Kaeng Krachan Reservoir. Then fertilized use can increase nutrient loading to the reservoir and its condition is suitable for phytoplankton growth. For the exciting condition of Huai Pak Subwatershed, there has many small mountains and has the rock base. In addition, its waterflow is usually high and very clear water. Although it is high nitrate concentration, its water quality is quite good and it meets the general condition of natural water.

Table 4.15 Comparison of some ecological parameters in four subwatersheds

Parameters	Phet-Bang Kloy Subwatershed	Mae Pradon Subwatershed	Huai Pak Subwatershed	Mae Prachan Subwatershed
Agricultural area (sq.km.)	0	0	110.57	211.18
Slope (%)	15 - 35	10 - 25	5 - 15	5 - 10
Maximum depth (m)	2.650 ± 1.756	5.113 ± 1.032	2.150 ± 0.613	0.808 ± 0.599
Transparency depth (m)	0.808 ± 0.370	1.233 ± 0.324	1.508 ± 0.579	0.567 ± 0.270
Suspended solid (mg/l)	**12.683 ± 7.744**	5.450 ± 4.029	3.417 ± 2.767	**19.371 ± 12.389**
Ammonium-nitrogen (ug/l)	1.700 ± 2.261	6.331 ± 3.218	10.555 ± 9.097	**23.285 ± 19.742**
Nitrite-nitrogen (ug/l)	1.350 ± 0.442	2.223 ± 0.868	3.572 ± 4.817	**7.230 ± 6.591**
Nitrate-nitrogen (ug/l)	**47.465 ± 44.041**	30.984 ± 36.063	**79.830 ± 54.887**	44.097 ± 41.478
Phosphate-phosphorus (ug/l)	6.679 ± 5.440	**9.706 ± 10.123**	6.197 ± 7.215	**17.310 ± 11.314**
Silica-silicon (mg/l)	10.049 ± 3.301	9.792 ± 4.049	8.621 ± 3.545	**14.364 ± 7.190**
Chlorophyll a (mg/m^3)	1.334 ± 0.917	**5.909 ± 6.424**	1.014 ± 0.550	3.317 ± 1.316

Note; ☐ = the highest value and different with other subwatersheds significantly at the $p = 0.05$
☐ = a high value different with some subwatersheds significantly at the $p = 0.05$

4.7 Ecological Condition of the Whole Watershed

According to table 4.16, ecological parameters varied among four subwatersheds. In subsystem I, there was high silica-silicon concentration and nitrate-nitrogen concentration at station P1 (the primitive forest area at head water, Phetchaburi River). This station had steep slope then there was high rate of soil erosion and high suspended solid. Although, station P1 had high nutrients, the chlorophyll *a* concentration was not high. Some conditions did not suitable for phytoplankton growth such as the high rate of streamflow and high turbidity in the wet season. Furthermore, it was very low water level in the dry season. It was the normal conditions at the head water or upstream of the watershed. Then water flowed down into station P3 (agricultural area at head water, Phetchaburi River) as outlet of subsystem I. Nitrate-nitrogen and phosphate-phosphorus concentrations were decreased. Station P3 was located above the reservoir then in the wet season, there was high volume of water. The flow of water was slower than upstream Then the condition in this river area was liked the reservoir. In addition, the nutrients and fertilizers were washed down into the river. Although the study found that some nutrients could be detected at low values, the nutrients changed forms and accumulated in phytoplankton biomass (Wetzel, 2001; Graham, 2000). It showed that phytoplankton bloomed in the wet season and chlorophyll *a* concentration was high in river system. The Cyanophyceae can bloom in the lakes and the rivers which were rich in nutrients when the flow was slow down. The plankton bloom indicated that this river area had eutrophication in the river during the wet season.

After that, the water flowed into the Kaeng Krachan reservoir (Subsystem II). Nitrate-nitrogen concentration and Phosphate-phosphorus concentration remained in low levels while chlorophyll *a* concentration was high but there were phytoplankton bloom in the wet season. The reservoirs received water that flowed from subsystem I and rainfall that washed away the agricultural land surrounding the reservoir. Thus, it supported phytoplankton growth. From meterrological data, it was rainy throughout the year 2002 (Pollution Control Department, 2003). Then high nutrients could be filled into the waterbodies (station P3 of subsystem I and station P4 in subsystem II).

Table 4.16 Comparison of the average values of some ecological parameters inputs and outputs in three subsystems of Phetchaburi Watershed

Ecological parameters	Subsystem I		Subsystem II	Subsystem III	
	station P1	station P3	station P4c	station P10	station P11
Transparency depth (m)	0.81 ± 0.37	**1.38 ± 0.30** *	**1.61 ± 0.46** *	0.31 ± 0.13 *♦	0.47 ± 0.13 *♦
Water temperature (°C)	24.85 ± 1.37	**28.22 ± 1.84** *	28.01 ± 2.20	29.58 ± 3.86 *♦	30.16 ± 2.99 *♦
pH -	7.25 ± 0.28	7.51 ± 0.22	**7.94 ± 0.32** *	6.72 ± 0.63 *♦	6.88 ± 0.45 *♦
Dissolved oxygen (mg/l)	8.12 ± 0.50	7.84 ± 0.38	**7.24 ± 0.57** *	5.30 ± 1.34 *♦	5.13 ± 0.84 *♦
Suspended solid (mg/l)	12.68 ± 7.74	**6.07 ± 5.50** *	4.21 ± 3.28	61.53 ± 26.80 *♦	40.90 ± 26.62 *♦
Ammonium-nitrogen (ug/l)	1.70 ± 2.26	2.26 ± 2.47	6.72 ± 11.43	24.36 ± 43.56 *♦	29.54 ± 56.67 *♦
Nitrite-nitrogen (ug/l)	1.35 ± 0.44	1.00 ± 0.49	1.24 ± 0.43	13.64 ± 9.14 *♦	19.34 ± 21.78 *♦
Nitrate-nitrogen (ug/l)	47.46 ± 44.04	6.77 ± 6.73	4.50 ± 7.16	77.67 ± 59.31 *♦	62.90 ± 51.87 *♦
Phosphate-phosphorus (ug/l)	6.68 ± 5.44	2.66 ± 2.24	1.99 ± 3.31	84.70 ± 34.98 *♦	88.97 ± 29.18 *♦
Silica-silicon(mg/l)	10.05 ± 3.30	9.04 ± 3.38	8.60 ± 3.96	3.84 ± 4.64 *♦	4.61 ± 5.32 *♦
Chlorophyll *a* content (mg/m³)	1.33 ± 0.92	**9.77 ± 5.22** *	**16.16 ± 9.69** *	66.47 ± 24.70 *	44.35 ± 18.34 *
Phytoplankton density (unit/m³)	5.04E+09 ± 4.74E+09	**1.48E+12 ± 2.36E+12** *	**6.48E+12 ± 5.12E+12** *	1.88E+11 ± 2.38E+11♦	3.08E+10 ± 4.08E+10

Note; Subsystem I (upstream), subsystem II (Kaeng Krachan Reservoir) and subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths)

* Difference is significant at the 0.05 level (2-tailed), ♦ station P10, P11 differ with station P1

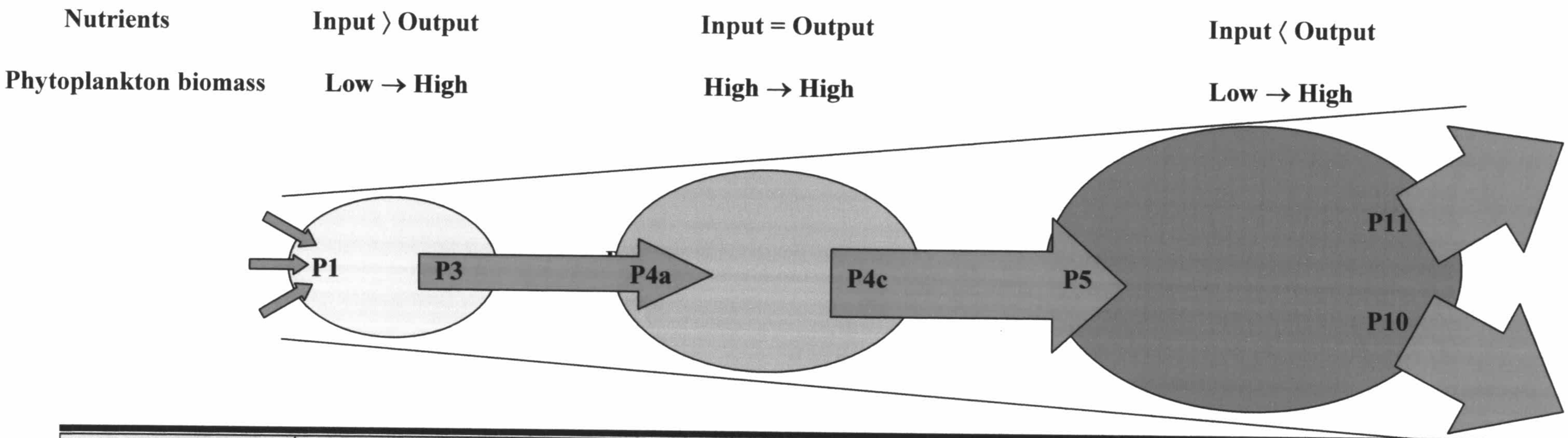
[light grey box] = station P3 differs with station P1, [dark grey box] = station P4 differs with station P3, [white box] = station P10 and P11 differ with station P4

However, the study detected low concentrations values of essential nutrients, the eutrophication in the reservoir indicated that subsystem IIwas rich in nutrients.

The water flowed down from subsystem II into the Phetchaburi River. Besides, the river had also received water from Huai Pak and Mae Prachan Subwatersheds. The nutrients were varied due to by many types of land use. The difference of nutrient concentrations was increased slightly in municipal area. However, Amphoe Maung has a drainage wastewater system so it can reduce nutrient concentrations at certain level in the river

Both Ban Lam and Bang Taboon river mouths (station P10 and P11) are the outputs of the watershed. Compared with the outputs of other subsystems, the two river mouths had very high nutrient concentrations that caused by various human activities in relation to land use patterns along the river to river month. In addition, Ban Laem river mouth had a higher nutrient concentration than Bang Taboon River mouth because Ban Laem had a lower flow rate than Bang Taboon. Moreover, there was a big fisherman village along the river bank at Ban Laem river mouth. The domestic wastewater directly discharges into the river with the additional wastewater from aquacuture while most of aquaculture increase nutrient concentration in the subsystem III.

Considering subsystem with 32.36 sq.km. (1.09%) of aquacultural area (Table 4.1; Figure 4.7) near the coastal zone, most of aquacuture directly discharge wastewater into the natural system (Pollution Control Department, 2001; The private questionnaire of this study).



Ecological parameters	The average values of some ecological parameters				
	Subsystem I		Subsystem II	Subsystem III	
	Input (station P1)	Output (station P3)	Output (station P4c)	Output (station P10)	Output (station P11)
Suspended solid (mg/l)	12.68 ± 7.74	**6.07 ± 5.50 ***	4.21 ± 3.28	**61.53 ± 26.80 ***	**40.90 ± 26.62 ***
Nitrate-nitrogen (ug/l)	47.46 ± 44.04	6.77 ± 6.73	4.50 ± 7.16	**77.67 ± 59.31 ***	**62.90 ± 51.87 ***
Phosphate-phosphorus (ug/l)	6.68 ± 5.44	2.66 ± 2.24	1.99 ± 3.31	**84.70 ± 34.98 ***	**88.97 ± 29.18 ***
Chlorophyll *a* content (mg/ m^3)	1.33 ± 0.92	**9.77 ± 5.22 ***	**16.16 ± 9.69 ***	**66.47 ± 24.70 ***	**44.35 ± 18.34 ***

Figure 4.59 Nutrients flow from subsystem I (upstream) to subsystem III (downstream) of the watershed

Note; * = Difference with station at the $p = 0.05$ level
[light grey box] = station P3 differs with station P1, [grey box] = station P4 differs with station P3, [white box] = station P10 and P11 differ with station P4

In conclusion, Phetchaburi Watershed composes of varied ecosystems and each subsystem has its own specific type. The major differences within each subsystem are seasons and system function. Figure 4.59 showed nutrients flow in the watershed from subsystem I (upstream), subsystem II (Kaeng Krachan Reservoir) to subsystem III (downstream)

An overview of subsystem I (upstream) shows that its ecology condition has changes significantly from headwater area to upstream area before entering into subsystem II (Kaeng Krachan Reservoir). At the headwater (station P1), there was high nutrient concentrations and a very low value of chlorophyll *a* concentration. After this streamflow passes through the agricultural area along upstream to the output of subsystem I (station P3). Although it could be detecetd low nutrient concentration, it highly increased in chlorophyll *a* concentration. This indicated that the output of subsystem I was enriched of nutrient and high primary production (chlorophyll *a*). Then subsystem I loss high nutrients out of its ecocsystem.

Subsystem II, the Kaeng Krachan Reservoir, which is classified as a lentic ecosystem, supported all living organisms to grow abundantly. The input of subsystem II was high chlorophyll *a* concentration.The result from the study showed that subsystem II had high chlorophyll *a* concentration. Phytoplankton had high photosynthesis rates when the ecosystem condition was enriched nutrient. It was seem the water ecosystem can recover itself. However, subsystem II could be considered as a mesotrophic-eutrophic reservoir, so then the system gave a very high primary production (chlorophyll *a* concentration) at the output of the subsystem (substation P4c).

Subsystem III were varied of land uses because streamflow to the river mouths is over a grater distance than other subsystems. Varied types of land use affect to the changing in nutrients and chlorophyll *a* concentration due to seasonal variation and water runoff. The river ecosystem can recover itself until approaching the municipal areas. After that, the water flowed pass the agricultural, especially aquacultural areas along the river mouths, the nutrient loading was become very high at the river mouths. In addition, Phosphate-phosphorus and nitrate-nitrogen concentrations at outputs of the subsystem III were very high different significantly with its input at the $p = 0.05$. It indicated that, chlorophyll *a* concentration of the output of subsystem III was different significantly with its input at the $p = 0.05$. Then subsystem III was loss high nutrients out of its ecocystem from Phetchaburi watershed to the gulf of Thailand.

Table 4.17 shows the comparison of surface water quality of the three subsystems on Phetchaburi Watershed with the Notification of water resources in the Phetchaburi River of the Pollution Control Department. Based on the standard surface water quality of Thailand, the water quality of almost all stations in the Phetchaburi Watershed was classified to be of the second to third category and was relatively suitable for fisheries and water supplies when properly treated (Pollution Control Department, 1997). However, by the trophic level, the reservoir can be classified as a mesotrophic and eutrophic types. All nutrient concentrations had tended to correlate within the seasons and rainfal. However, it must be concern that the suspended solid

Table 4.17 Comparison of the Standard Surface Water Quality Classification and trophic status of three subsystems on Phetchaburi Watershed

Area boundary in the study	**Distance from the river Mouth (km)**	**Standards of Surface Water Quality Classification of Thailand**		
		Pollution Control Department, 1999	**Pollution Control Department, 2002**	**Present study**
Subsystem I	Head watershed (120 – 210 km)	-	-	**1** * **(Oligotrophic)** #
	The upper end of Kaeng Krachan Reservoir (120)	-	**2** (WQI = 72)	**2*** **(Mesotrophic -Eutrophic)** #
Subsystem II	Kaeng Krachan Reservoir	-	-	**2*** **(Mesotrophic -Eutrophic)** #
Subsystem III	Phetchaburi Dam to Kaeng Krachan Reservoir (61 – 118)	**2**	**2** (WQI = 62 – 71)	**2** * **(Mesotrophic)** #
	River Mouths to Phet Dam (0 – 61)	**3**	**3** (WQI = 40-63)	**3** * **(Mesotrophic -Eutrophic)** #

Note; * = Water Quality Index of the Phetchaburi River (Pollution Control Department, 1997)

= Trophic type (Wetzel, 2001) (Appendix G)

Subsystem I = upstream, subsystem II = Kaeng Krachan Reservoir and subsystem III = downstream from Kaeng Krachan Reservoir to the river mouths at Mae Prachan Subwatershed was high throughout the year. It must be concern that the nutrient enrichments at the areas above and in the Kaeng Krachan Reservoir, and Phetchaburi and Bang Taboon River Mouths. Then phytoplankton could bloom in the area of river mouths.Besides, Pollution Control Department (2003) reported that there were many times of phytoplankton bloom occurred many times the Gulf of Thailand., the dominant species must be monitored because some toxic phytoplankton might be bloom in eutrophic status.

According to the Pollution Control Department (2003) report, in 2002 the surface water quality in all regions of Thailand were better than that in 2001 (Figure 4.60) because of an increased of rainfall throughout the year. It was the same as the inland areas on the watershed of this study. Most of the surface water levels, tested during the investigation (December 2001 to October 2002) did not exceed the surface water standard of Thailand.

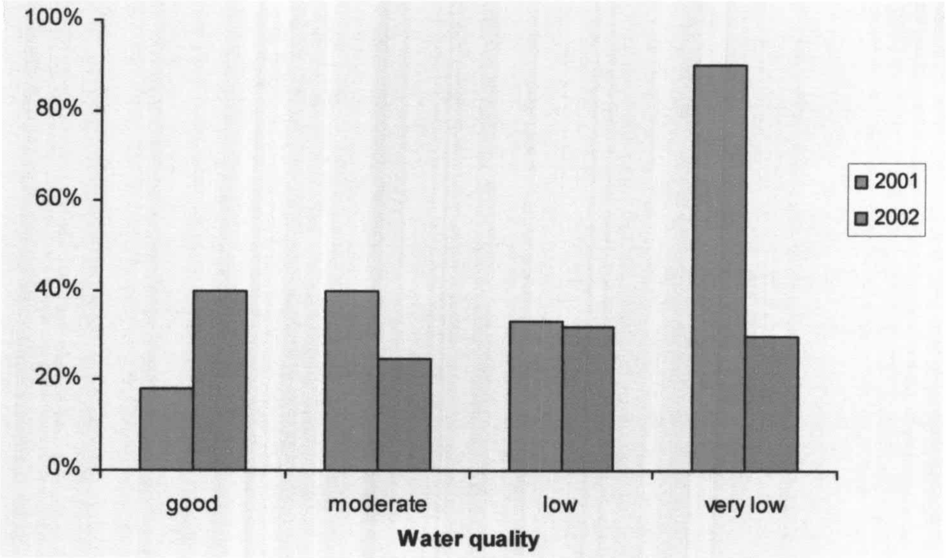


Figure 4.60 Comparison percentage of Thailand water quality between year 2001 and 2002

Source; Pollution Control Department, 2003

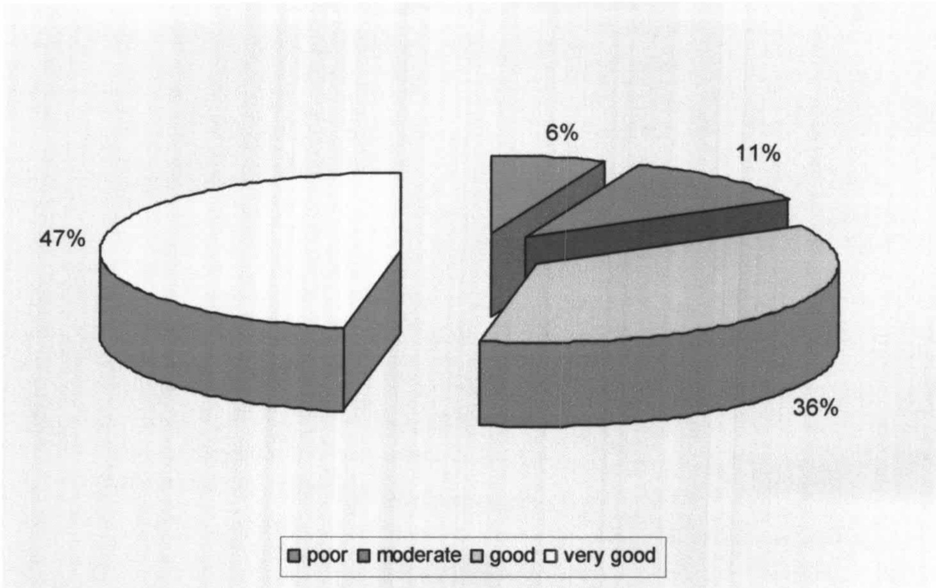


Figure 4.61 Percentage of Thailand costal water qualities in year 2002
Source; Pollution Control Department, 2003

In contrast the water quality at the Ban Laem and Bang Taboon river mouths were low. The result of the study corresponds to the report from the Pollution control department (2003). The report found that the coastal water quality in year 2002 had poor quality at 6 percent and all areas were within the gulf of Thailand (Figure 4.61). These were the Rayong river mouth, Rayong Province; Ban Laem and Bang Taboon river mouths, Phetchaburi Province, and the Pattani river mouth, Pattani Province.

4.8 Socio-Economic Parameters

The study of the local people's participation in the sustainable watershed management: a case study of Phetchaburi Watershed was randomly selected from people in Phetchaburi Province. The objectives of the study were to determine the level of participation, other factors affecting participation of people, additional problems and suitable guidelines for the sustainable watershed management. The data was gathered from the 409 sample cases through questionnaires.

The population sample was selected from eight Amphoes of Phetchaburi Province. The 409 respondents were composed of male and female at 46.7 and 53.3 percent, respectively. Ages of the respondents varied from 17 to 72 years old. The majority group was the 41 - 50 years old at 23 percent and the rest 7.6 percent were 17 - 20 years old. Marital status of the respondents the highest group was married at 73.1 percent and the second group was single at 22.7 percent single.

The respondents were divided into three groups based on the area of the subsystems. The 66, 124 and 219 respondents were interviewed from subsystem I, II and III, respectively (Table 4.18).

Table 4.18 The population sample of Phetchaburi people

Characteristic of participants	Percentage	Number
Total number	100	409
Locality		
Subsystem I		66
Amphoe Kaeng Krachan (Ban Pong – Luk and Ban Bang – Kloy)		
Subsystem II		124
Amphoe Kaeng Krachan (surrounding Kaeng Krachan Reservoir)		
Subsystem III		219
Amphoe Maung		
Amphoe Khou Yoi		
Amphoe Nong Ya Plong		
Amphoe Cha-am		
Amphoe Tha Yang		
Amphoe Ban Laem		

4.8.1 Socio-Economic Parameters of Population in Subsystem I (Upstream) of Phetchaburi Watershed

4.8.1.1 Socio-Economic Characteristic of Population Samples in Subsystem I

The population sample was selected from subsystem I who were 66 respondents from Amphoe Kaeng Krachan (the area of head water of Phetchaburi Watershed). The respondents live in two villages, Ban Pong Luk and Ban Bang Kloy. Almost of them are hill Tribe called Karang people.

The respondents were composed of male and female at 47.0 and 53.0 percent, respectively (Table 4.19). Ages of the respondents varied from 16 to 72 years old. The majority group was the 31 - 40 years old at 28.8 percent and the rest 3.0 percent were more than 61 years old and higher. Marital status of the respondents, the highest group was married at 92.4 percent and the second group was single at 7.6 percent. The highest group of membership in household was 6 persons and more at 45.5 percent.

Concerning the respondents' education, the highest percentage was no education at 72.2 percent, the second highest percentages was primary school at 19.7 percent and the third highest percentages were junior high school and high school at 4.5 percent.

Concerning the occupation of the respondents, the 68.2 percent were agriculterists and 18.2 percent were workers. The 13.6 percent were find officers,traders and students.

Concerning the length of time that the respondents stay in the village, the highest group was at 31 - 40 years at 28.8 percent. The two groups of 21 - 30 years and 41 - 50 years were of similar percentage at 24.2 and 21.2, respectively.

The respondents' monthly incomes were surveyed and a majority group earned from less than 3,000 baht at 80.3 percent. The second largest group earned from 3,001 – 6,000 baht (16.7 percent). The lowest groups who earned 6,001 - 9,000 baht and 9,001 - 12,000 baht were at 1.5 percent.

Concerning the social appointment status of the respondents, 40.9 percent were in social position and 59.1 percent were never in social positions.

With regard to consumed water consumption, all respondents used direct from Phetchaburi River and rain water. In addition, all of them release wastewater into the ground.

Concerning the respondents' sources of information about the environmental conservation, all respondents had monthly meeting in the village. In addition, the highest group at 97.0 percent got the information news about "once a while" (1 - 2 time per month). The lowest percentages were "often" level (1 - 2 time per week) and "never" receiving any news at 1.5 percent.

Concerning with regard to the respondents' diaster experiences, the highest percentage was from drought at 78.8 percent. The second percentage was from flood at 13.6 percent. However the 7.5 percent had never suffered.

Table 4.19 Socio-economic characteristic of respondents in Subsystem I

Socio-economic characteristics	Percentage	Number
Sex		
Male	47.0	31
Female	53.0	35
Age		
20 years and lower	13.6	9
21 - 30 years old	24.2	16
31 - 40 years old	28.8	19
41 - 50 years old	24.2	16
51 - 60 years old	6.1	4
61 years and higher	3.0	2
Education		
No education	72.2	47
Primary school	19.7	13
Junior high school	4.5	3
High school/ Vocational Education	4.5	3
Marital status		
Single	7.6	5
Married	92.4	61

Table 4.19 Socio-economic characteristic of respondents in Subsystem I (Cont.)

Socio-economic characteristics	Percentage	Number
Number of children		
No children	13.1	8
1 person	14.7	9
2 persons	16.4	10
3 persons	8.2	5
4 persons	11.5	7
5 persons	16.4	10
6 persons	8.2	5
7 persons	6.6	4
8 persons	4.9	3
Membership in household		
1 person	1.5	1
2 persons	1.5	1
3 persons	13.6	9
4 persons	21.2	14
5 persons	16.7	11
6 persons and more	45.5	30
Occupation		
Student	1.5	1
Officers	10.6	7
Private Business	1.5	1
Worker	18.2	12
Agriculturists	68.2	45
Length of time staying in the village		
1 - 10 years	6.1	4
11 - 20 years	10.6	7
21 - 30 years	24.2	16
31 - 40 years	28.8	19
41 - 50 years	21.2	14
51 - 60 years	7.6	5
61 - 70 years	1.5	1
Income		
<3000 baht	80.3	53
3001 - 6000 baht	16.7	11
6001 - 9000 baht	1.5	1
12001 - 15000 baht	1.5	1
Social status		
Having no position, non-member of a committee	59.1	39
Have (had) a position	40.9	27
Water supply		
River / canal	100.0	66

Table 4.19 Socio-economic characteristic of respondents in Subsystem I (Cont.)

Socio-economic characteristics	Percentage	Number
Water drainage		
Release to the ground	100.0	66
Conservation news		
Meeting/ documents in village, community	100.0	66
Frequency of conservation news		
Often (1 - 2 time per week)	1.5	1
Once in a while (1 - 2 time per month)	97.0	64
Never receive any news	1.5	1
Disaster experiences		
Flood	13.6	9
Drought	78.8	52
Never	7.6	5

4.8.1.2 The general knowledge in Phetchaburi Watershed management and the participation of people on the conservation of Phetchaburi Watershed

The general knowledge in Phetchaburi Watershed management, the participation and the desire for participation was measured by a questionnaire with a total of 11, 20 and 10 items, respectively. Afterward, all of the scores were brought together and percentages were used to organize the levels. The three levels of the general knowledge in Phetchaburi Watershed were presented as follow:

Low level (0 - 39%)
Moderate level (40 - 69%)
High level (70 - 100%)

And the three levels of the participation and the want of participation were presented as follow:

Low level (0 - 30%)
Moderate level (31 - 70%)
High level (71 - 100%)

From the study, it was found that the highest group had the moderate level of general knowledge about Phetchaburi Watershed management at 71.2 percent. The high level and the low level were at 25.8 and 3.0 percent, respectively (Table 4.20).

Concerning the level of participation in Phetchaburi Watershed management, the highest group was at the high level at 50.5 percent. The moderate level was 45.5 percent.

Concerning the desire for participation in Phetchaburi Watershed management, the highest group was the moderate level at 69.5 percent. There were 19.7 percent of participants at the high level. Only 10.6 percent of participants were at the low level.

Table 4.20 Percentage of the level of knowledge, the participation of people on conversation and desire for participation in Phetchaburi Watershed management of Phetchaburi Watershed in Subsystem I

The Level	Percentage	Frequency
The level of general knowledge in Phetchaburi Watershed management		
Low level	3.0	2
Moderate level	71.2	47
High level	25.8	17
The level of participation in Phetchaburi Watershed management		
Moderate level	45.5	30
High level	50.5	36
The level of the desire for participation in Phetchaburi Watershed management		
Low level	10.6	7
Moderate level	69.7	46
High level	19.7	13

4.8.1.3 Willingness to pay to support the sustainable watershed management

Table 4.21 presents the willingness to pay for sustainable Phetchaburi watershed management. The results showed that all respondents or 100 percent agreed and were willing to pay to support the activity for sustainable Phetchaburi Watershed management. In addition, all respondents would like to contribute by labor and most of them were willing to donate their labor force every month at 92.4 percent.

Table 4.21 The willingness to pay to support the activity for Phetchaburi Watershed management in Subsystem I

Characteristic	Percentage	Frequency
Would you be willingness to pay to support the activity for sustainable Phetchaburi Watershed management?		
Yes	100.0	66
No	0.0	0
How do you pay for your contribution?		
By labor	100.0	66
By cash	0.0	0
How often do you willing to donate your labor force?		
Once a year	3.0	2
Every month	92.4	61
Other (every time)	4.5	3
The major reason of the donation		
Aware to the essential and benefit of activities and these activities can be succeeded	83.3	55
Consider as a meritorious activities	16.7	11

4.8.1.4 The Relationships of the socio-economic parameters of subsystem I

The results of the relationships of the socio – economic parameters in subsystem I can be shown in Table 4.22. Based on the analysis, it was found that gender had a negative correlation to a higher level of the general knowledge in watershed management, the participation and the desire for participation in the watershed management significantly at the $p = 0.01$. It meant that male had had a higher level of the general knowledge in watershed management, the participation and the desire for participation in their watershed than females.

Considering the study, it found that age had a positive correlation to the general knowledge in watershed management significantly at the $p = 0.05$. It meant that the older had a higher level of general knowledge in the watershed management than the younger.

The results found that the educational level had a positive correlation to the general knowledge in watershed management, the participation, the desire for participation and the donation for watershed conservation projects significantly at the $p = 0.01$. These results showed that people with higher education were of a higher level of the general knowledge in watershed management, the participation and the desire to participation than those with lower education.

Apparently, the duration of living in the watershed had tended to be positive correlation with the general knowledge in watershed management, the participation, and the desire for participation. While the study found that the social appointment status had a positive correlation to the participation and the desire to participation significantly at the $p = 0.01$. Furthermore, the social appointment status had a positive correlation to the donation for watershed conservation projects significantly at the $p = 0.05$. People who were in the position of social appointment status had a higher level of the general knowledge in watershed management, the participation and the desire for participation and donation for watershed conservation projects in their watershed than those who never were the social position.

The results found that the levels income had a positive correlation to the donation for watershed conservation projects significantly at the $p = 0.01$. It had also positive correlation with the desire for participation significantly at the $p = 0.05$. People who had higher income had of a higher level of desire to participate and the donate for watershed conservation projects than those who had lower income.

According to the study, the frequency of the information about the watershed had a positive correlation to the general knowledge in watershed management, the participation and the desire for participation significantly at the $p = 0.01$ level. It had also positive correlation with the donation for watershed conservation projects significantly at the $p = 0.05$. The people who received more frequency of information had a higher level of participation in their watershed than those who received less frequency of information about their watershed.

With regard to the local people in subsystem I, the study found that the general knowledge in watershed management had also positive correlation with the participation and the desire for participation significantly at the $p = 0.01$.

Table 4.22 The correlation of socio-economic parameters in subsystem I

		Sex	Age	Education	Living time	Income	Social position	frequency of news	knowledge in watershed	activity in participation	want in participation	agree conservation	donation	type of donation
Spearman's *rho*	Sex	1											-0.086	
	Age	-.414(**)	1											
	Education	-.426(**)	0.045	1										
	Living time	-.398(**)	.914(**)	-0.054	1									
	Income	-0.229	0.076	.461(**)	-0.028	1								
	Social position	-.390(**)	0.072	.494(**)	0.027	.294(*)	1							
	frequency of news	-.329(**)	0.037	.669(**)	0.05	.374(**)	.548(**)	1						
	knowledge in watershed	-.386(**)	.246(*)	.384(**)	0.201	0.163	.569(**)	.451(**)	1					
	activity in participation	-.371(**)	0.09	.332(**)	0.068	0.141	.512(**)	.399(**)	.376(**)	1				
	want in participation	-.358(**)	0.147	.547(**)	0.085	.272(*)	.428(**)	.396(**)	.440(**)	.387(**)	1			
	agree conservation	.	.	.	.	.	.	.	.	.	.	.		
	donation	-0.086	0.018	.401(**)	-0.208	.461(**)	.262(*)	.243(*)	0.201	0.199	0.236	.	1	
	type of donation	-.389(**)	0.098	.619(**)	0.028	.615(**)	.536(**)	.744(**)	.395(**)	.374(**)	.432(**)	.	.386(**)	1

Note;
- Correlation is significant at the 0.0001 level (2-tail)
- Correlation is significant at the 0.001 level (2-tail)
- Correlation is significant at the 0.01 level (2-tail)
- Correlation is significant at the 0.05 level (2-tail)

4.8.2 Socio-Economic Parameters of Population in Subsystem II (Kaeng Krachan Reservoir) of Phetchaburi Watershed

4.8.2.1. Socio-Economic Characteristic of Population Samples in Subsystem II

The population sample was selected from subsystem II who were 124 respondents from Amphoe Kaeng Krachan (all area of this Amphoe expected Ban Pong-Luk and Ban Bang-Kloy). The respondents were interviewed by using questionnaires and presented as follow;

The respondents were composed of male and female at 49.2 and 50.8 percent, respectively (Table 4.23). Ages of the respondents varied from 17 to 68 years old. The majority group was the 41 -50 years old at 30.6 percent and the rest 5.6 percent were 20 years old and lower. Marital status of the respondents the highest group was married at 83.9 percent and the second group was single at 13.7 percent. The highest membership in household was 4 persons at 24.2 percent.

Concerning the respondents' education, the highest percentage was from primary school at 59.7 percent, the second highest percentages were junior high school and high school/vocational education at 10.5 percent and the third highest percentage was no education at 8.9 percent. The two groups of high vocational education and graduate level were of similar percentage at 5.6 and 4.8, respectively.

Concerning the occupation of the respondents, the highest group was agriculturist at 25.0 percent. The second highest group was worker at 22.6 percent. The theird groups of find officers, traders and fishermen were of similar percentage at 17.7, 12.9 and 11.3, respectively.

Concerning the length of time that the respondents stay in the village, the highest group was at 31 - 40 years at 33.9 percent. The two groups of 21 - 30 years and 41 - 50 years were of similar percentage at 23.4 and 19.4, respectively.

The respondents' monthly incomes were surveyed and a majority earned from 3,001 – 6,000 baht (32.3 percent). The second largest group earned less than 3,000 baht (24.2 percent). The third group was of no income (14.5 percent) and the groups who earned 6,001 – 9,000 baht and 9,001 – 12,000 baht were similar percentage at 12.1 and 8.9, respectively. The lowest groups who earned 18,001 – 21,000 baht was at 0.8 percent.

Concerning the social appointment status of the respondents, 37.1 percent were in social position and 62.9 percent were never in social position.

With regard to about water consumption, the 37.1 percent use water direct from Kaeng Krachan Reservoir. The 32.3 and 19.4 percent used water from tap water and underground water, respectively.

Concerning the wastewater management of respondents, the highest group was at 66.9 percent released wastewater into canal, river, reservoir and the sea. The 24.2 percent of respondents released wastewater into drainage pipes and the other groups released water into the ground and released into the ground through the waste filter at 5.6 and 3.2 percent, respectively.

Concerning the respondents' sources of information about the environmental conservation, it was found that the highest group of 33.1 percent got information from television. The second highest group of 28.1 percent got information from the community meeting. In addition, the highest group at 46.8 percent got the information about "once a while" (1 – 2 times per month). The second highest group at 28.2 percent got the information about at "often level" (1 – 2 times per week). The lowest group at 1.5 percent "never" receives any news.

With regard to the repondents and their disasters experiences, the highest percentage never had disaster 45.2 percent. The second and the third highest percentage were from drought and flood at 21.0 and 18.5 percent, respectively.

Table 4.23 Socio-economic characteristic of respondents in Subsystem II

Socio-economic characteristics	Percentage	Number
Sex		
Male	49.2	61
Female	50.8	63
Age		
20 years and lower	5.6	7
21 - 30 years old	9.7	12
31 - 40 years old	25.8	32
41 - 50 years old	30.6	38
51 - 60 years old	12.1	15
61 years and higher	16.1	20
Education		
No education	8.9	11
Primary school	59.7	74
Junior high school	10.5	13
High school/ Vocational Education	10.5	13
High Vocational education	5.6	7
Graduate level	4.8	6
Marital status		
Single	13.7	17
Married	83.9	104
Window/Divorced/Separate	2.4	3
Number of children		
No children	13.7	17
1 person	5.6	7
2 persons	15.3	19
3 persons	24.2	30
4 persons	16.1	20
5 persons	10.5	13
6 persons	5.6	7
7 persons	3.2	4
8 persons	2.4	3
9 persons	3.2	4
Membership in household		
1 person	3.2	4
2 persons	10.5	13
3 persons	21.8	27
4 persons	24.2	30
5 persons	21.8	27
6 persons and more	18.5	23

Table 4.23 Socio-economic characteristic of respondents in Subsystem II (Cont.)

Socio-economic characteristics	Percentage	Number
Occupation		
Student	4.8	6
Officers	17.7	22
Private Business	12.9	16
Worker	22.6	28
Agriculturist	25.0	31
Fishery/breeding aquatic animal	11.3	14
Housewife / no occupation	4.8	6
Others	0.8	1
Length of time staying in the village		
1 - 10 years	5.6	7
11 - 20 years	11.3	14
21 - 30 years	23.4	29
31 - 40 years	33.9	42
41 - 50 years	19.4	24
51 - 60 years	4.0	5
61 - 70 years	1.6	2
71 - 80 years	0.8	1
Income		
No income	14.5	18
<3000 baht	24.2	30
3001 - 6000 baht	32.3	40
6001 - 9000 baht	12.1	15
9001 - 12000 baht	8.9	11
12001 - 15000 baht	4.8	6
15001 - 18000 baht	2.4	3
18001 - 21000 baht	0.8	1
Social status		
Having no position, non-member of a committee	62.9	78
Have (had) a position	37.1	46
Water supply		
Tap water	32.3	40
Rain water	8.1	10
Underground water	19.4	24
River / canal	3.2	4
Direct from Kaeng Krachan Dam	37.1	46
Water drainage		
Release to drain pipe	24.2	30
Release to canal / river / reservoir / sea	66.9	83
Release to the ground	5.6	7
Release to the ground through the waste filter	3.2	4

Table 4.23 Socio-economic characteristic of respondents in Subsystem II (Cont.)

Socio-economic characteristics	Percentage	Number
Conservation news		
Radio	8.1	10
Television	33.1	14
Newspaper	1.6	2
Meeting/ documents in village, community	28.2	35
Meeting/ document from working place/ school	8.9	11
Local radio in village	9.7	12
Others	10.5	13
Frequency of conservation news		
Very often (3 - 4 time per week)	16.9	21
Often (1 - 2 time per week)	28.2	35
Once a while (1 - 2 time per month)	46.8	58
Never receive any news	8.1	10
Disaster		
Flood	18.5	23
Wildfire	3.2	4
Drought	21.0	26
Soil erosion	6.5	8
Others	5.6	7
Never	45.2	56

4.8.2.2. The general knowledge in Phetchaburi Watershed management and the participation of local people in subsystem II

From the study, It was found that the highest group and the second highest group had the moderate and high level of general knowledge about Phetchaburi Watershed management at 46.8 and 44.4 percent, respectively. The low level was at 8.9 percent. (Table 4.24)

Concerning the level of participation in Phetchaburi Watershed management, the highest group was the moderate level participators at 41.9 percent. The high level participators were at 37.9 percent. And the lowest group was the low level participators at 20.2 percent.

Concerning the desire for participation in Phetchaburi Watershed management, the highest group would like to participate was in the moderate level at 68.5 percent. There were 29.0 percent of participants at the high level. Only 2.4 percent of at participants were at the low level.

Table 4.24 Percentage of the level of knowledge, the participation of people on conversation and desire for participation in Phetchaburi Watershed management of Phetchaburi Watershed in Subsystem II

The Level	Percentage	Frequency
The level of general knowledge in Phetchaburi Watershed management		
Low level	8.9	11
Moderate level	46.8	58
High level	44.4	55
The level of participation in Phetchaburi Watershed management		
Low level	20.2	25
Moderate level	41.9	52
High level	37.9	47
The level of the desire for participation in Phetchaburi Watershed management		
Low level	2.4	3
Moderate level	68.5	85
High level	29.0	36

4.8.2.3. Willingness to pay to support the sustainable watershed management

Table 4.25 presents the willingness to pay for sustainable Phetchaburi watershed management. The results showed that the most respondents or 97.6 percent agreed and willing to pay to support the activity for sustainable Phetchaburi Watershed management. The 57.3 percent of respondents would like to contribute by labor and 41.1 percent by cash. The 54.9 percent of respondents who would contribute by labor were willing donate their labor every month while the 35.2 percent were willing donate once a year.

Table 4.25 The willingness to pay to support the activity for Phetchaburi Watershed management in Subsystem II

Characteristic	Percentage	Frequency
Would you be willingness to pay to support the activity for sustainable Phetchaburi Watershed management?		
Yes	97.6	3
No	2.4	121
How do you pay for your contribution?		
By labor	57.3	71
By cash	41.1	51
Other Food, instrument	1.6	2
How often do you willing to donate your labor force?		
Once a year	35.2	25
Every month	54.9	39
Other (every time)	9.9	7
How often do you willing to donate your money?		
Once a year	70.6	36
Every month	29.4	15
The major reason of the donation		
Aware to the essential and benefit of activities and these activities can be succeeded	84.7	105
Consider as a meritorious activities	8.1	10
At present, conservation trend is highly considered by everybody as shown in many media	4.8	6
Other	2.4	3

4.8.2.4. The relationships of socio – economic parameters of subsystem II

The results of the relationships of the socio – economic parameters in subsystem II can be shown in Table 4.26. Based on the analysis, it was found that gender had a negative correlation to the participation significantly at the p = 0.01. It meant that males had had a higher level of the participation in their watershed than females.

According to the study, it was found that age had slightly negative correlation with the general knowledge in watershed management participation, the desire for participation and the donation for watershed conservation projects. It meant that the younger had a higher level of the general knowledge in the watershed management than the older.

Considering to the study, the educational level had a positive correlation to the general knowledge in watershed management significantly at the $p = 0.01$. In addition, the education level had a positive correlation to the general knowledge in the watershed management significantly at the $p = 0.05$. These results showed that people with higher education had a higher level of the general knowledge in watershed management than those with lower education.

Apparently, the duration of living in the watershed had tended to be positive correlation with the general knowledge in watershed management and the participation. While the study found that the social appointment status had a positive correlation to the participation significantly at the $p = 0.01$. People who were in the position of social appointment status had a higher level of the participation in their watershed than those who never were in any social position.

The results found that the different levels ofcome had a positive correlation to the participation and desire for participation significantly at the $p = 0.01$. It had also positive correlation with the general knowledge in watershed management and the participation significantly at the $p = 0.05$. It showed that people who had higher income also have a higher level of the general knowledge in watershed management, participation and the desire for participation than those who had lower income.

According to the study, the frequency of the information about the watershed had a positive correlation to the desire to participate significantly at the p 0.01. In addition, it had a positive correlation to the general knowledge in watershed management significantly at the p 0.05. The people who received more frequency of information had a higher level of the general knowledge in watershed management and the desire to participate in the watershed than those who received less frequency of information about their watershed.

Considering the local people in subsystem I, the study found that the general knowledge in watershed management had also positive correlation with the participation and the desire to participate significantly at the $p = 0.01$. In addition, the participation had a positive correlation to the desire for participation significantly at the $p = 0.01$.

Table 4.26 The correlation of socio-economic parameters in subsystem II

		Sex	Age	Education	Living time	Income	Social position	Frequency of news	Knowledge in watershed	activity in participation	want in participation	Agree conservation	donation	type of donation
Spearman's rho	Sex	1												
	Age	0.061	1											
	Education	-0.169	-.471(**)	1										
	Living time	0.123	.420(**)	-.197(*)	1									
	Income	-0.049	-0.096	.350(**)	0.063	1								
	Social position	-0.146	0.024	0.006	0.115	0.028	1							
	frequency of news	-0.112	-.232(**)	.364(**)	0.054	.306(**)	0.126	1						
	knowledge in watershed	-0.001	-0.169	.230(*)	0.153	.189(*)	0.172	.183(*)	1					
	activity in participation	-.235(**)	-0.086	0.165	0.025	.259(**)	.320(**)	0.157	.249(**)	1				
	want in participation	-0.156	-0.038	.326(**)	-0.018	.279(**)	0.13	.231(**)	0.034	.351(**)	1			
	agree conservation	0.092	-0.135	0.04	0.069	0.075	0.069	0.062	0.062	0.134	0.051	1		
	donation	0.055	-0.116	0.07	0.017	0.115	-0.096	-0.009	0.015	-0.026	0.09	-0.014	1	
	type of donation	.182(*)	0.146	0.099	.200(*)	.222(*)	-0.035	0.013	0.016	0.018	.190(*)	0.072	.249(**)	1

Note;
- Correlation is significant at the 0.0001 level (2-tail)
- Correlation is significant at the 0.001 level (2-tail)
- Correlation is significant at the 0.01 level (2-tail)
- Correlation is significant at the 0.05 level (2-tail)

4.8.3 Socio-Economic Parameters of Population in Subsystem III (downstream from Kaeng Krachan Reservoir to the river mouths) of Phetchaburi Watershed

4.8.3.1 Socio-economic characteristic of local people in subsystem III

The population sample was selected from seven Amphoes of Phetchaburi Province The sample size of local people in subsystem III was 219 respondents. The respondents were composed of male and female at 45.2 and 54.8 percent, respectively (Table 4.27). Ages of the respondents varied from 17 to 56 years old. The majority group was higher than 60 years old 23.3 percent and the rest 7.3 percent were 18 - 20 years old. However, four groups, those from 21 - 30, 41 -50, 31 - 40 and 51 - 60 years old had similar percentage at 19.2, 18.3, 17.4, 15.1 percent, respectively. Marital status of the respondents the highest group was married at 61.2 percent and the second group was single at 32.4 percent.

Concerning the membership in household, the highest percentage was 4 persons at the 23.3 percent. The second highest and the third highest percentage were similar percentage at 21.0 and 20.1 from 5 and 6 persons, respectively. The average membership in houseshold was 4 persons.

Concerning the respondents' education, the highest percentage was from primary school at 39.7 percent, the second highest percentage was graduate level at 14.3 percent and the third highest percentage was high school/vocational level at 13.9 percent. The lowest percentage was from both higher graduate level and no education at 1.8 percent.

Concerning the occupation of the respondents, the highest group was traders at 22.8 percent. The second highest group was workers at 24.2 percent and the third highest group was find officers at 12.3 percent.

Concerning the length of time that the respondents stay in the village, the highest group was at 31 - 40 years at 20.0 percent, the second highest and the third highest groups were at 21 – 30 and 41 – 50 years at 18.3 and 17.4 percent, respectively. The third groups of 11 - 20 years, 61 - 70 years and 51 - 60 years were of similar percentage at 12.8, 11.9 and 10.0, respectively.

The respondents' monthly incomes were surveyed and a majority earned from 3,001 – 6,000 baht (33.1 percent). The second largest group earned less than 3,000 baht (16.4 percent). The third group was of no monthly income (14.2 percent) and the groups who earned 15,001 – 18,000 baht and 18,001 – 21,000 baht were same percentage at 3.2 percent, respectively. The lowest groups who earned 21,000 – 24,000 baht and more than 30,000 baht were at 0.5 percent.

Concerning the social appointment status of the respondents, 29.3 percent were in social position and 70.7 percent never were in social position.

With regard to water consumption, 91.8 percent used tap water and 3.7 percent used direct underground water. The 3.2 percent used water from rain water, and the lowest percentage used water from the river and canal was at 1.4 percent.

Concerning the wastewater management of respondents, the highest group at 53.0 percent released waste water into the drainage pipes. The 27.9 percent of respondents released waste water into the canal, the river and the sea. The other groups were 11.7 and 7.3 percent of respondents released water into the ground and released water into the ground through the waste filter.

Concerning the respondents sources of information about the environmental conservation, it was found that the highest group of 43.4 percent got the information from television. The second highest and the third highest group of 17.8 and 12.3 percent got the information from the meeting in the community and the local radio in the village, respectively. 47.9 percent of the respondents got the information about "once a while" (1 – 2 times per month). Two groups of the respondents 22.8 and 21.0 percent received the information about at "often" level (1 – 2 time per week) and very "freauent" level (3 – 4 time per week), respectively.

Concerning with regard to the respondents and disaster, the highest percentage was from flood at 53.0 percent. The 28.8 percent of respondents had never suffered disaster.

Table 4.27 Socio-economic characteristic of respondents in Subsystem III

Socio-economic characteristics	Percentage	Number
Sex		
Male	45.2	99
Female	54.8	120
Age		
20 years and lower	6.8	15
21 - 30 years old	19.2	42
31 - 40 years old	17.4	38
41 - 50 years old	18.3	40
51 - 60 years old	15.1	33
61 years and higher	23.3	51
Education		
No education	1.8	4
Primary school	39.7	87
Junior high school	15.1	33
High school/ Vocational Education	16.4	36
High Vocational education	5.9	13
Graduate level	19.2	42
Higher graduate level	1.8	4
Marital status		
Single	32.4	71
Married	61.2	134
Window/Divorced/Separate	6.4	14
Number of children		
No children	28.3	62
1 person	7.3	16
2 persons	15.1	33
3 persons	20.1	44
4 persons	12.8	28
5 persons	5.9	13
6 persons	1.4	3
7 persons	2.3	5
8 persons	4.1	9
9 persons	2.7	6

Table 4.27 Socio-economic characteristic of respondents in Subsystem III (Cont.)

Socio-economic characteristics	Percentage	Number
Membership in household		
1 person	6.8	15
2 persons	12.3	27
3 persons	16.4	36
4 persons	23.3	51
5 persons	21.0	46
6 persons and more	20.1	44
Occupation		
Student	9.6	21
Officers	12.3	27
Private Business	30.6	67
Worker	24.2	53
Agriculturist	3.2	7
Fishery/breeding aquatic animal	5.9	13
Housewife / no occupation	9.1	20
Retirement	4.6	10
Other	0.5	1
Length of time staying in the village		
<1 year	1.4	3
1 - 10 years	3.7	8
11 - 20 years	12.8	28
21 - 30 years	18.3	40
31 - 40 years	21.0	46
41 - 50 years	17.4	38
51 - 60 years	10.0	22
61 - 70 years	11.9	26
71 - 80 years	3.7	8
Income		
No income	14.2	31
<3000 baht	16.4	36
3001 - 6000 baht	31.1	68
6001 - 9000 baht	12.8	28
9001 - 12000 baht	5.9	13
12001 - 15000 baht	8.2	18
15001 - 18000 baht	3.2	7
18001 - 21000 baht	3.2	7
21001 - 24000 baht	0.5	1
24001 - 27000 baht	1.8	4
27001 - 30000 baht	2.3	5
>30000 baht	0.5	1

Table 4.27 Socio-economic characteristic of respondents in Subsystem III (Cont.)

Socio-economic characteristics	Percentage	Number
Social status		
Having no position, non-member of a committee	74.9	164
Have (had) a position	25.1	55
Water supply		
Tap water	91.8	201
Rain water	3.2	7
Demin water	3.7	8
River / canal	1.4	3
Water drainage		
Release to drain pipe	53.0	116
Release to canal / river / reservoir / sea	27.9	61
Release to the ground	11.9	26
Release to the ground through the waste filter	7.3	16
Conservation news		
Radio	8.7	19
Television	43.4	95
Newspaper	5.9	13
Meeting/ documents in village, community	17.8	39
Meeting/ document from working place/ school	1.4	3
Local radio in village	12.3	27
Others: Please indicate	10.5	23
Frequency of conversation news		
Very often (3 - 4 time per week)	21.0	46
Often (1 - 2 time per week)	22.8	50
Once in a while (1 - 2 time per month)	47.9	105
Never receive any news	8.2	18
Disaster experiences		
Flood	53.0	116
Drought	4.6	10
Soil erosion	0.5	1
Coastal storm	12.8	28
Others	0.5	1
Never	28.8	63

4.8.3.2 The general knowledge in Phetchaburi Watershed management and the participation of local people in subsystem III

From the study, It was found that the highest group had a high level of general knowledge about Phetchaburi Watershed management at 49.8 percent. The moderate level and the low level were at 42.8 and 8.2 percent, respectively (Table 4.28)

Concerning the level of participation in Phetchaburi Watershed management, the highest group was the moderate level participators at 43.4 percent. The low level participators were at 40.6 percent. And the lowest group was the high level participators at 16.0 percent.

Concerning the desire for participation in Phetchaburi Watershed management, the highest group wanting to participate was in the moderate level at 63.9 percent. There were 26.5 percent of participants at the high level. Only 9.6 percent of at participants were at the low level.

Table 4.28 Percentage of the level of knowledge, the participation of people on conversation and desire for participation in Phetchaburi Watershed management of Phetchaburi Watershed in Subsystem III

The Level	Percentage	Frequency
The level of general knowledge in Phetchaburi Watershed management		
Low level	8.2	18
Moderate level	42.0	92
High level	49.8	109
The level of participation in Phetchaburi Watershed management		
Low level	40.6	89
Moderate level	43.4	95
High level	16.0	35
The level of the desire for participation in Phetchaburi Watershed management		
Low level	9.6	21
Moderate level	63.9	140
High level	26.5	58

4.8.3.3 Willingness to pay to support the sustainable watershed management

Table 4.29 presents the willingness to pay for sustainable Phetchaburi watershed management. The results showed that the most respondents or 95.9 percent were willing pay to support the activities of Phetchaburi Watershed management. The 29.0 percent of respondents would like to contribute by labor and 71.0 percent by cash (Table 4.15). The 45.9 percent of the respondents who would contribute by labor were willing to donate their labor force once a year. While the 47.6 percent of the respondents who contribute by cash were willing to donate their money once a year and the 26.9 percent of the respondents welcomed to donate their money every month.

Table 4.29 The willingness to pay to support the activity for Phetchaburi Watershed management in Subsystem III

Characteristic	Percentage	Frequency
Would you be willingness to pay to support the activity for sustainable Phetchaburi Watershed management?		
Yes	95.9	210
No	4.1	9
How do you pay for your contribution?		
By labor	29.0	61
By cash	71.0	149
How often do you willing to donate your labor force?		
Once a year	26.2	16
Every month	45.9	28
Other (every time)	27.9	17
How often do you willing to donate your money?		
Once a year	47.6	71
Every month	26.9	40
Other (all time)	25.5	38
The major reason of the donation		
Aware to the essential and benefit of activities and these activities can be succeeded	73.5	161
Consider as a meritorious activities	6.8	15
At present, conservation trend is highly considered by everybody as shown in many media	5.9	13
Other	13.7	30

4.8.3.4 The relationships of the socio-economic parameters of subsystem III

The results of the relationships of the socio-economic parameters in subsystem III can be shown in Table 4.30. Based on the analysis, it was found that gender had a negative correlation to the participation and the desire for participation in the watershed management significantly at the p = 0.01. In addition, gender had also negative correlation with the general knowledge in watershed management significantly at the p = 0.05. It meant that males had had be of a higher level of the general knowledge in watershed management, the participation and the desire of participation in their watershed than females.

According to the study, it found that age had a negative correlation to the general knowledge in watershed management significantly at the p = 0.05. It meant that the younger had a higher level of the general knowledge in the watershed management than the older.

The results found that the educational level had a positive correlation to the general knowledge in watershed management and the participation significantly at the p = 0.01. Besides, the education level had a positive correlation to the desire for participation significantly at the p = 0.05. These results showed that people with higher education had a higher level of the general knowledge in watershed management, the participation and the desire for participation than those with lower education.

Apparently, the duration of living in the watershed had tened to be positive correlation with the general knowledge in watershed management and the participation. While the study found that the social appointment status had a positive correlation to the participation significantly at the p = 0.01. People who were in the position of social appointment status were of a higher level of the participation in their watershed than those who never were the position.

The results found that the different levels of income had a positive correlation to the desire for participation significantly at the $p = 0.01$. It had also positive correlation with the general knowledge in watershed management and the participation significantly at the $p = 0.05$. It showed that people who had higher income had a higher level of the general knowledge in watershed management, the participation and the desire to participation than those who had lower income.

According to the study, the frequency of the information about the watershed had a positive correlation to the participation significantly at the p 0.05. The people who received more frequency of information had a higher level of participation in their watershed than those who received less frequency of information about their watershed.

Considering the local people in subsystem III, the study found that the general knowledge in watershed management had also positive correlation with the participation and the desire for participation significantly at the $p = 0.01$. In addition, the general knowledge in watershed management and the agreement in conservation had a positive correlation to the donation for watershed conservation projects significantly at the $p = 0.01$.

Table 4.30 The correlation of socio-economic parameters in subsystem III

		Sex	Age	Education	Living time	Income	Social position	Frequency of news	Knowledge in watershed	Activity in participation	Want in participation	Agree conservation	Donation	Type of donation
Spearman's rho	Sex	1												
	Age	-0.061	1											
	Education	-0.061	-.403(**)	1										
	Living time	-0.049	.730(**)	-.291(**)	1									
	Income	-.207(**)	0.016	.404(**)	0.037	1								
	Social position	-0.066	0.088	0.029	0.085	0.041	1							
	frequency of news	-0.035	-.169(*)	.279(**)	-0.129	.168(*)	0.027	1						
	knowledge in watershed	-.155(*)	-.144(*)	.335(**)	-0.049	.136(*)	0.083	0.101	1					
	activity in participation	-.196(**)	-0.067	.216(**)	0.079	.133(*)	.344(**)	.165(*)	.183(**)	1				
	want in participation	-.184(**)	0.06	.142(*)	0.046	.189(**)	0.009	0.094	.185(**)	.209(**)	1			
	agree conservation	0.016	-0.013	-0.059	0.05	0	0.033	-0.018	0.09	0.068	0.029	1		
	donation	-0.083	-0.009	-0.049	0.014	0.052	-0.06	0.098	.134(*)	-0.021	.190(**)	.474(**)	1	
	type of donation	-0.047	0.08	0.049	0.078	0.108	-0.028	0.002	0.118	-0.073	0.06	0.002	.260(**)	1

Note;
- Correlation is significant at the 0.0001 level (2-tail)
- Correlation is significant at the 0.001 level (2-tail)
- Correlation is significant at the 0.01 level (2-tail)
- Correlation is significant at the 0.05 level (2-tail)

The result of the study found that local people at downstream have participated in sustainable watershed management of Phetchaburi Watershed were in the moderate level category. The study, contrasted to the study of Somsaaj (1996) which found that people who had participated on the project of water bank were in the low level category. In addition, the study was also different with the study of Supon (2002) which found that people who had participated in the conservation of environment at Budha Udhayan Water Reservoir, Amnatchareon Province were in the low level category.

However, after considering the group questionnaire, it was found that most of the respondents had moderate to high levels of motivation. In addition, the respondent's trend was to respond with high willingness to pay for activities in sustainable watershed management. Obviously, most people had a high level of knowledge about the Phetchaburi Watershed that had a positive correlation to the participation, the desire for participation and the donation for conservation of the Phetchaburi Watershed. So, it should be successful to support and give information to the local people of Phetchaburi in order to increase the level of participation in their watershed management.

The increasing of watershed conservation education might bring higher demand of participation to people, which may lead to sustain watershed management. Moreover, the social statuses; formal leaders, religious leaders, volunteer correlated with the demand of participation. According to Udomwech *et al.*, (1999) indicated that there are many volunteered groups in Phetchaburi Province who concerned in environmental issues. Thus, to promote participation of watershed management should co-ordinate with these volunteer groups.

4.9 Integrated ecological condition and socio-economic with land use patterns on Phetchaburi Watershed

The impacts of loss and degradation of forests are in the form of soil erosion, loss of biological diversity, damage to wildlife habitats and degradation of watershed areas, deterioration of the quality of life and reduction of the options for development (EPA, 1992).

The load of sediments discharged into the oceans by the great rivers of the world tells us something about human abuses of the land (Odum, 1997). The rivers of Asia, the continent with the oldest civilizations and the most intense human pressure on the land, discharge 1500 tons of soil per square mile of land area drained by the river annually. In contrast, the sediment discharge rate for North America is 245, South American 160 and Europe 90 tons of soil per square mile of land area drained annually (Holeman, 1968 in Odum, 1997). Increasing pressure from the public and environment bodies will ensure that land and water resource planners will have to take full account of natural conservation and the sustainable watershed in the policy and plan.

To discuss the Phetchaburi Watershed Management, it clearly understands to integrate information in each subsystem as follows:

Subsystem I lies in the area of upstream of Phetchaburi Watershed. Majority of the area within this subsystem is in the Kaeng Krachan National Park. According to ecological study, it is found that this water subsystem is in a normal condition but areas of Mae Pradon Subwatershed and above Kaeng Krachan Reservoir have been degraded especially water quality. All these factors indicate that areas above the reservoir are quite fertile. Furthermore, when taking land use into account, it is found that the area along the Phetchaburi River and Mae Pradon subwatershed is used for agriculture with chemical fertilizer use. Lastly, the areas are somewhat steep and are lied next to the river. As a result, it increases the rate of soil erosion and brings nutrient into the water bodies.

For area of head water of Phetchaburi and Bang Kloy Subwatershed, it is found that ecological conditions are in good and annual change is in relevant to its geography. Here, there are two villages of tribes – Bang Kloy Village and Pong-Luk Village. Most of people in the villages work on agriculture. Approximately 120 villages along Phetchaburi River and in control of border patrol department, Ministry of Defence and the officer of Kaeng Krachan National Park.

70% of all households, are living in Bang Kloy Village is likely to have problems of limited agricultural land. It might lead to environmental problem in the near future if the government do not implement a proper management plan. People have done shifting cultivation since long time ago before an announcement of this national park until governors provided a place for them to live and do agriculture. In contrast to the Bang Kloy Villagers, 30 % of people living Pong Luk Village, did not have any problem due to these people have stayed very long time ago before this area has been announced as national park. Therefore, each household has area for their agriculture and so next to the river. No movement for a new settlement as same as place for agriculture. It makes quality of life and economy security of people in this village to be better than people in Bang Kloy village.

There has been more villagers practice agriculture, more fertilizers and chemicals use to maximize the productivity. As a result, there is high degradation of land in cultivated areas. Mae Pradon Subwatershed is a good example for this case. Moreover, some Karang people move into the other areas of national park when the productivity is not satisfied. This might lead to the conflict between them and the park rangers as happened in the past. In addition, people's life style and type of house should be improved to be durable and strong in order to facilitate them to stay permanently. This can reduce the use of forest resource as they do not have to change it every often.

Another interesting point from this study shows that Karang tribes have more than six children on average due to lack of family planning and young marriage. About one year (April 2002 – August 2003), Bang Kloy Village has been increased about 12 household additionally. Therefore a proper agricultural management could not encounter with population increase. This also causes a problem of higher natural resources uses in the National Park in the future.

Although 100% of Karang people have a possibility to participate in the watershed conservation in high level, it could not guarantee that this behavior based on external force or good attitude. However, many activities have been arranged by the park officers so it can be a force to trigger people with good attitude. If these activities are not efficient in the cooperating people and the officers, they might not be allowed to use the park for agriculture or they have to move to other areas that are suitable for their land use activities in the future. It is because, as we know, negative impacts, caused by people's inappropriate activities have affected degradation in watershed area as well as economic and social problems of people in that area.

Subsystem II covers Kaeng Krachan Reservoir and area around the dam in Kaeng Krachan District. Majority of the area is in the national park. The reservoir is under the responsibility of Irrigation Department. Most area in subsystem II is a water source for people in Phetchaburi watershed. The water quality could be characterized as level 2 and 3 according to the standard surface water quality under the notification of the Pollution Control Department. However, in rainy season, nutrients are flowed from upstream into the reservoir and cause a plankton bloom. If this situation is severe, it might generate toxic which can harm organisms in water as well as people, in surrounding area. Moreover, people who consume water directer from the reservoir will also face with this problem. Consequently, price of water supply from fabricated irrigation system will be increased.

As for people's occupation, most people have worked on agriculture and trade on agricultural products. Only a small number have worked on tourism. Differences in land use utilization affect the ecological system in different ways. Not only agriculture around the dam affects a great deal of nutrients loading, drained into the dam but also wastewater from households causes the plankton bloom. Regarding to the interviews, migration of Karang has been increased. They have moved to stay around and above the reservoir . It increases number of labor force and agricultural area which result in an increase in the rate of soil erosion and generate nutrients into the reservoir and can make it shallow.

In controlling water flow into the reservoir, there should be an accurate calculation of water release to be corresponded to purposes. In general, the reservior facilitates water supply for agriculture, electricity generation, flood control and saltwater intrusion into the Phetchaburi River. However, the reservior also become and attractive recreation site for water sport and activities such as fishing, rafting, etc. In the year 2003, there was a conflict between the officers and tour agencies/bussiness about the water regulation (Personal communication). The tour agencies/bussiness request the officers open the gate for facilitating water throughout the year. This cause decrease water level in the dry season. Then both stakeholders are trying to make the agreement together to meet their own needs.

For economic and social issues, it is found that people are in a middle class. They satisfy with an infrastructure provided. They also have a good attitude toward participating in watershed conservation project. As people have stayed in the reservoir area, they have seen how important the reservoir is. Therefore, to follow the plan for watershed management by promoting some activities to contribute knowledge to people should be a key to conserve natural resources in this area.

Subsystem III is the biggest area of all three subsystems. Land uses here definitely differ from subsystem I and II, especially for residential area and industry in floodplain downstream and aquaculture in the river mouth areas.

People living downstream practice agriculture and sell agricultural products. Utilization of land for industry has been increased from the downtown Phetchaburi to the Gulf of Thailand. Aquaculture has replaced mangrove areas so the natural forest is less than that in the past. The water quality here is acceptable and meet the standard of the government. However, there was a phytoplankton bloom during the rainy season at the river mouths when there was high sediment and nurient loading .

Along the Huai Pak Subwatershed, the water quality meets the standard although it is surrounding with agricultural practice. As the area of Mae Prachan Subwatershed, the geographical characteristics are floodplain and hills with areas of agriculture along the river. The precipitation is so high in the rainy season that is likely to cause flooding especially when there is heavy rain consecutively. At present, there is a project of dam construction in order to solve the problem of flooding. According to the observation, the stream was very shallow and turbid, and some area was even dried out.

The water quality of Phetchaburi River before entering municipal area is not very good but still meets the standard. When water passes through the town, nutrient contents are not increased much due to the good wastewater treatment in Laem Phak Bia Project. Additionally, there will be a plan to increase the pipes for pumping water to the treatment plant.

After this water flowing to the town, it flows through agricultural land and aquaculture area along river banks, coast, and mangrove fringe. This increases high amount of nutrients and change the quality of water. Water in the area of river mouths including Ban Laem and Bang Taboon River Mouths are brackish. Consequently, there is very diverse group of phytoplankton especially the salt-tolerant group. In Ban Laem River Mouth, sometimes in the river mouth area, there were phytoplankton blooms as fisheries settled down there and the water drained into the river mouth directly. Conversely, in Bang Taboon River Mouths, because the river mouth is broader and water flows faster, the runoff drained to the Gulf of Thailand easier. Thus, the water quality is better.

Although ecological conditions and water quality of this downstream is developing and being improved, the problem is the phytoplankton bloom. This indicates that there is high amount of nutrient, released from the watershed. Another thing that should be put into consideration is to educate people to appropriately use the land so that the ecological conditions will be the recovered.

As social and economic status, people living downstream have better living than those who live upstream. However, people living upstream have more participation in water conservation more than people downstream. It is because people down there do not know much about the Kaeng Krachan Reservoir and just satisfy that they have tap water to use. Therefore, it must educate people to have more concern and answers on natural resource conservation throughout the watershed areas.

Concerning the land use pattern of Phetchaburi Province (National Statistical Office, 2002), the land use was a little different from 1991 to 1998. In 1998, the land use types were categorized into 3 types those were 106,260.8 ha of farm holding land; 214,474.56 ha of forest land and 301,778.4 ha of other land uses (Figure 4.62). Farmland was divided in many land use types (Figure 4.63). The highest areas was paddy fields at 51% (53,528.8 ha) of total farmland. Orchard and plantation covered areas of 22% (23,722.08 ha). Cash crops covered area of 15% (15,960.16 ha). The remaining of 13% were residential areas, vegetable and flower gardens, animal farmlands, abandoned land, and other lands. However, many farm holding areas such as; orchard and cash crop had low agricultural products and were not worthwhile to invest in. According to Land Development Department (1999) reported that the farmers in the upper part of Phetchaburi River were not worthwhile in their products. Then they were not good economic status. The report indicated that these areas were unsuitable land uses, low water supply in the dry season. In addition, local people had low education and low knowledge in agriculture.

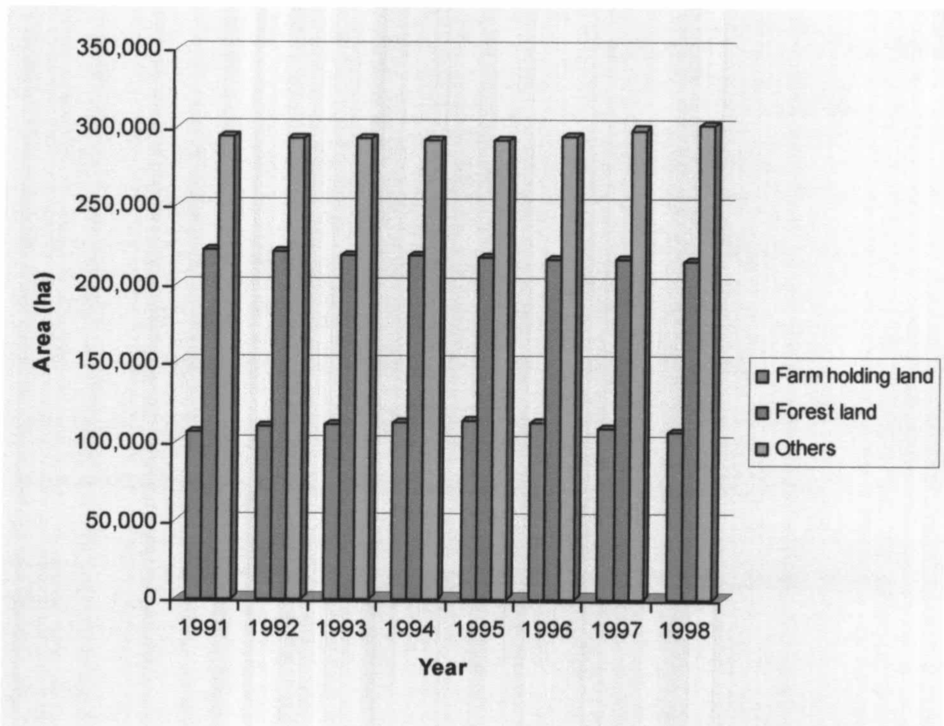


Figure 4.62 Land utilization of Phetchaburi Province in 1991 - 1998

Source: National statistical office (2002)

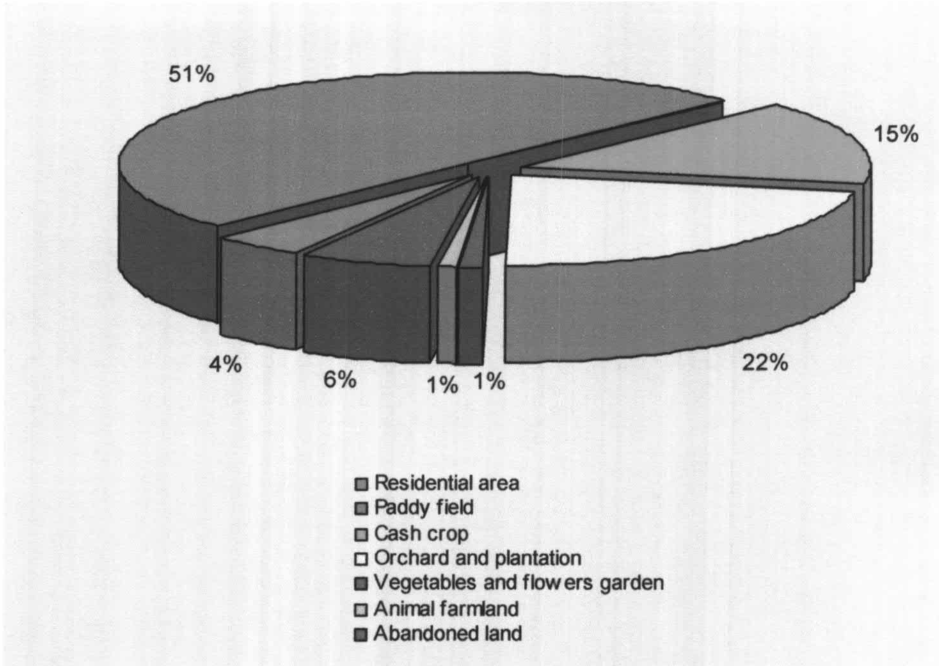


Figure 4.63 Utilization of farm holding land in Phetchaburi Province in 1998
Source: National statistical office (2002)

Therefore, it indicated that the proportion of land-use patterns is quite stable; it also corresponds to the low percentage of people immigration as 3.5% with staying in local community less than 10 years. However, it is also necessary to consider the population growth, which potentially causes the land-use change pressure in the future.

According to the land utilization data, most people in Phetchaburi Province depend on agricultural activities, so the water resources are very important for their living. To solve the problems of water resources degradation in Phetchaburi watershed in relation to various causes and effects, it needs to strengthen involvement of all participators who involve either directly or indirectly with water utilization in the different subsystems.

This study also presented a simple model for future research. An adequate modeling should be base on the establishment of a data bank and information system encompassing ecological, social and economic components. The model will address the integrated and predictive the sustainable watershed management. Figure 4.65 presented an adaptive and integrated model of watershed management.

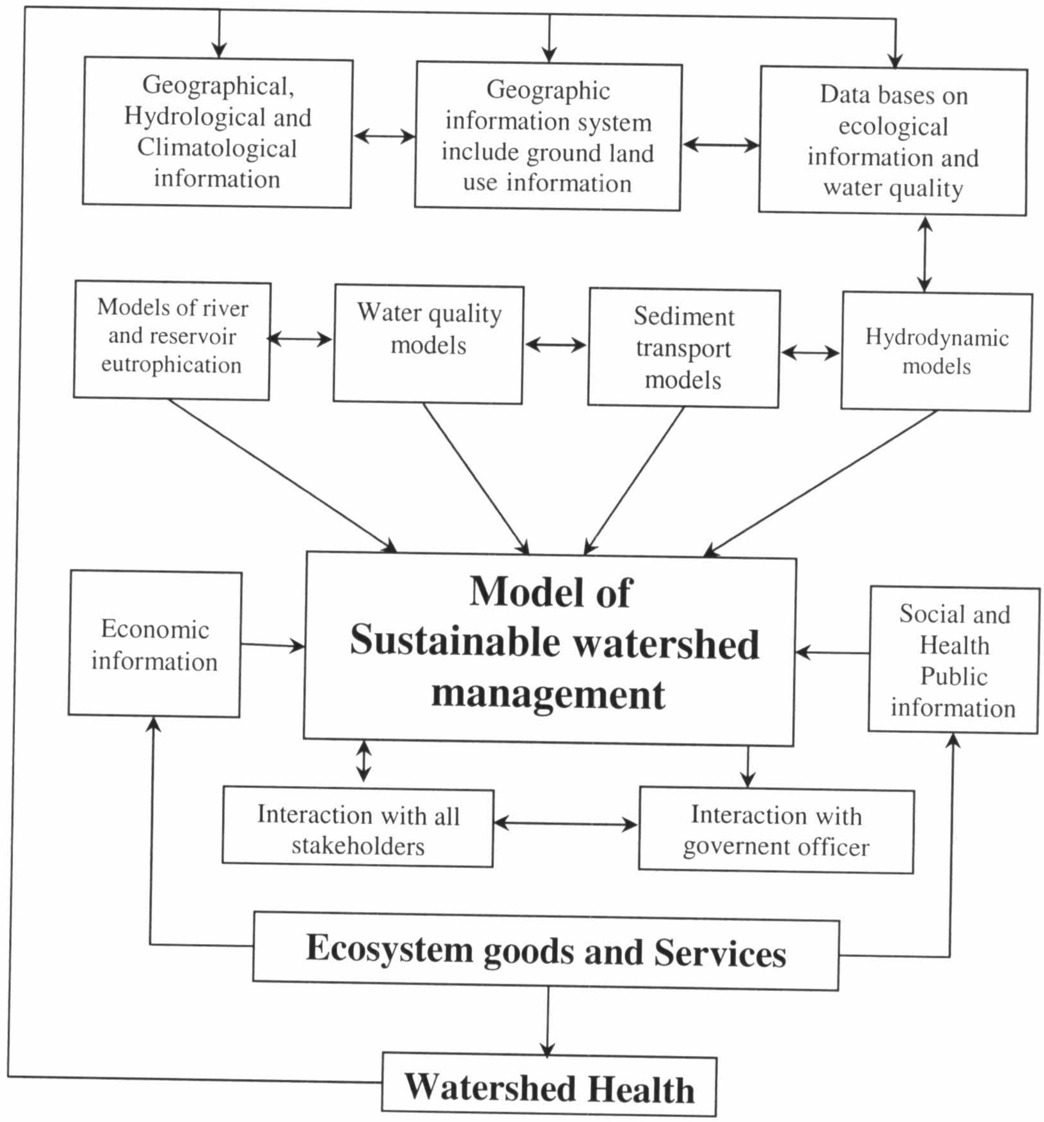


Figure 4.64 An Adaptive Model of Phetchaburi Watershed Management