Seasonal Water Flow Trends in Conjunction with Phytoplankton Biovolume in Petchburi River, Thailand

Visi Asriningtyas[1*], Chadnaree Meesukko[2], Nantana Gajaseni[3] and Alexey Voinov[4]

This research of seasonal water flow trends in conjunction with water quality in the Petchburi River, Thailand is a watershed analysis concerted at subwatershed scale. We focused on water flow as the physical abiotic parameter in conjunction with phytoplankton biovolume as the biotic parameter. This research depicts how the physical landscape of the watershed, soil and landuse, effect the flow of the river and its water quality.

The water flow was analyzed using WMS v.7.0 (public domain) and other relevant hydrologic formulas to show that different types of subwatersheds (developed or undeveloped) produce different runoff to the river. Water quality at each point of measurement was different, depending on the characteristics of flow. Wet season phytoplankton biovolumes for lentic or close to lentic systems such as at the input to Kaeng Krachan Reservoir, 945.05 x 10^9 unit/m^3 and estuary, 573.21 x 10^9 unit/m^3 are higher than those of the dry season (7.54 x 10^9 unit/m^3 and 1.09 x 10^9 unit/m^3 respectively). Dry season phytoplankton biovolumes for some lotic (river) systems (P1, 4.89 x 10^9 unit/m^3; P2, 6.15 x 10^9 unit/m^3; and P8, 1.10 x 10^9 unit/m^3) were higher than those of the wet season (0.31 x 10^9 unit/m^3, 0.03 x 10^9 unit/m^3, 0.88 x 10^9 unit/m^3 respectively). An alternative method of flow assessment in conjunction with water quality is proposed for systems with scarce data available.

Key words: Petchburi River, water flow, phytoplankton biovolume and alternative method of flow assessment.

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ปริมาณน้ำตามฤดูกาลที่มีผลต่อ Phytoplankton Biovolume ในแม่น้ำเพชรบุรี, ประเทศไทย

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การวิจัยปริมาณน้ำตามฤดูกาลที่มีผลต่อ Phytoplankton Biovolume ในแม่น้ำเพชรบุรี, ประเทศไทย เป็นการวิเคราะห์ความสัมพันธ์ระหว่าง การวิเคราะห์ปริมาณน้ำในขนาดพื้นที่ลุ่มน้ำย่อย กับปริมาณ phytoplankton biovolume เพื่ออธิบายถึงผลกระทบของภูมิทัศน์ทางกายภาพของพื้นที่ลุ่มน้ำ ลักษณะของดิน และลักษณะของการใช้ที่ดิน ที่มีผลต่อพฤติกรรมน้ำหลาก และคุณภาพของน้ำ

การวิเคราะห์พฤติกรรมน้ำหลาก จะใช้โปรแกรม WMS v.7.0 (public domain) และทฤษฎีทางอุทกวิทยาที่เกี่ยวข้องเพื่อแสดงความแตกต่างของลักษณะพื้นที่ลุ่มน้ำที่มีผลต่อปริมาณน้ำหลากลงสู่แม่น้ำ คุณภาพของน้ำที่จุดวัดจะมีผลแตกต่างกันขึ้นกับลักษณะการไหลของน้ำ ผลการวิจัยพบว่าในฤดูที่มีปริมาณน้ำมาก phytoplankton biovolume สำหรับพื้นที่ lentic หรือใกล้กับ lentic system เช่นที่ P3 (อ่างเก็บน้ำแก่งกระจาน มีค่า 945.05 x10^9 unit/m^3) และที่ P10 (573.21 x10^9 unit/m^3) จะสูงกว่าฤดูกาลที่มีปริมาณน้ำน้อย (7.54 x10^9 unit/m^3 และ 1.09 x10^9 unit/m^3 ตามลำดับ) ในขณะที่ในฤดูกาลที่มีน้ำน้อย phytoplankton biovolume สำหรับพื้นที่ lotic (แม่น้ำ) P1 (4.89 x10^9 unit/m^3) P2 (6.15 x10^9 unit/m^3) P8 (1.10 x10^9 unit/m^3) จะมีค่ามากกว่าในฤดูกาลที่มีน้ำมาก (0.31 x10^9 unit/m^3, 0.03 x10^9 unit/m^3 และ 0.88 x10^9 unit/m^3 ตามลำดับ) นอกจากนี้ได้เสนอทางเลือกในการวิเคราะห์ค่า flow assessment ที่มีผลต่อคุณภาพของน้ำในกรณีที่มีข้อมูลดิบน้อยด้วย

คำสำคัญ แม่น้ำเพชรบุรี ปริมาณน้ำ phytoplankton biovolume การวิเคราะห์ค่า flow assessment

INTRODUCTION

Background of Research

The Petchburi Watershed is one of twenty-five main watersheds in Thailand. It covers an area of approximately 4700 square km; that is most of the area of Petchburi Province and some parts of Samut Songkram Province and Ratchaburi Province. Geographically. Only the main channel of the watershed is called Petchburi River, and it is approximately 210 km from the headwater to the estuary. The Petchburi Watershed is located between UTM 47 1480000 N, 510000 E and 1390000 N, 610000 E in Southwest Thailand. The watershed is contagious to the Mae Klong Watershed in the north, Prachuab Khiri Khan Province in the south, the Gulf of Thailand in the east, and the international border of Myanmar in the west. The research location and stream network is shown in Figure 1.

Based on secondary data of Petchburi province, the climate of the area is classified as tropical. The air temperature ranges from 25.6 to 39.5°C. The coldest month is January and the hottest is April. The average monthly air temperatures in the year 2002 were slightly higher than average monthly temperatures from 1981 to 2001. There are two seasons, wet and dry, in the area. The wet season is from May to October and the dry season is from November to April.

The most fundamental interactions between a lotic ecosystem and its catchment area concern the input of water and chemicals[(21)] There is an interesting contrast in the principal patterns of abiotic features in lotic and lentic environments. In deep ponds and lakes many ecologically important physico-chemical factors, including temperature, light intensity, and oxygen concentration, vary vertically as Revealed in distinct depth profiles. In rivers, on the other hand, horizontal, or longitudinal patterns and intensity of abiotic factors can usually be discerned from headwaters to the mouth[21]. Phytoplankton abundance and composition in aquatic ecosystems are regulated by abiotic mechanisms such as nutrients related to physical-chemical variability and biotic, trophic interaction[(18)] However, the relationship between phytoplankton dynamics and environmental change is still poorly understood in many regions of the world.[(10)]

Ecological factors which consist of the abiotic and biotic properties of the watershed is an interesting field to be studied. In this study river flow, as the physical abiotic factor, is estimated in conjunction with phytoplankton biovolume as the biotic parameter. Phosphate-P, which is one of the chemical abiotic factors is also presented to give a better depiction of how the ecosystem behaves at a certain point in the watershed and at a certain time. Water quality was assessed using secondary data to give a depiction of the trend of river flow in dry and wet season in conjunction with water quality data (mainly phytoplankton biovolume). The magnitude and duration of flows coupled with the chemical quality of the water determines, to a considerable degree, the biological characteristics of the stream.[(20)] The river system was therefore considered from the physical, chemical, and biological perspectives.[(20)]

Study Site

This study used a topographic map, scale 1 : 50,000 dated 2001 as the base map for geographic database of the area. Thematic maps used in this study were:

1. The land use map of scale 1 : 50,000 of Petchburi, Samut Songkram and Ratchaburi Provinces, dated 2001.
2. The soil map of scale 1 : 50,000 of Petchburi, Samut Songkram and Ratchaburi Provinces, dated 1988.

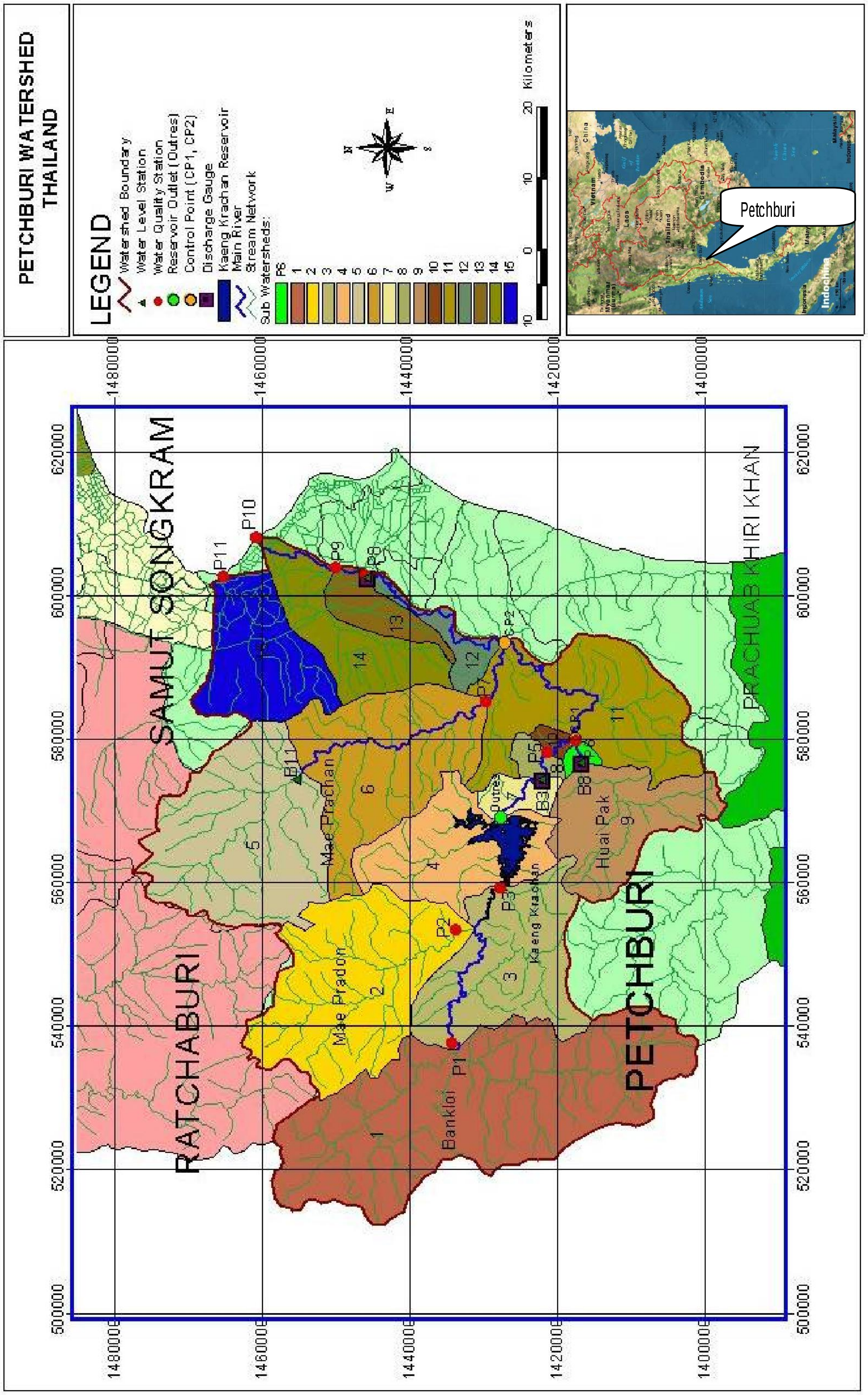


Figure 1. Petchburi Watershed Study Site.

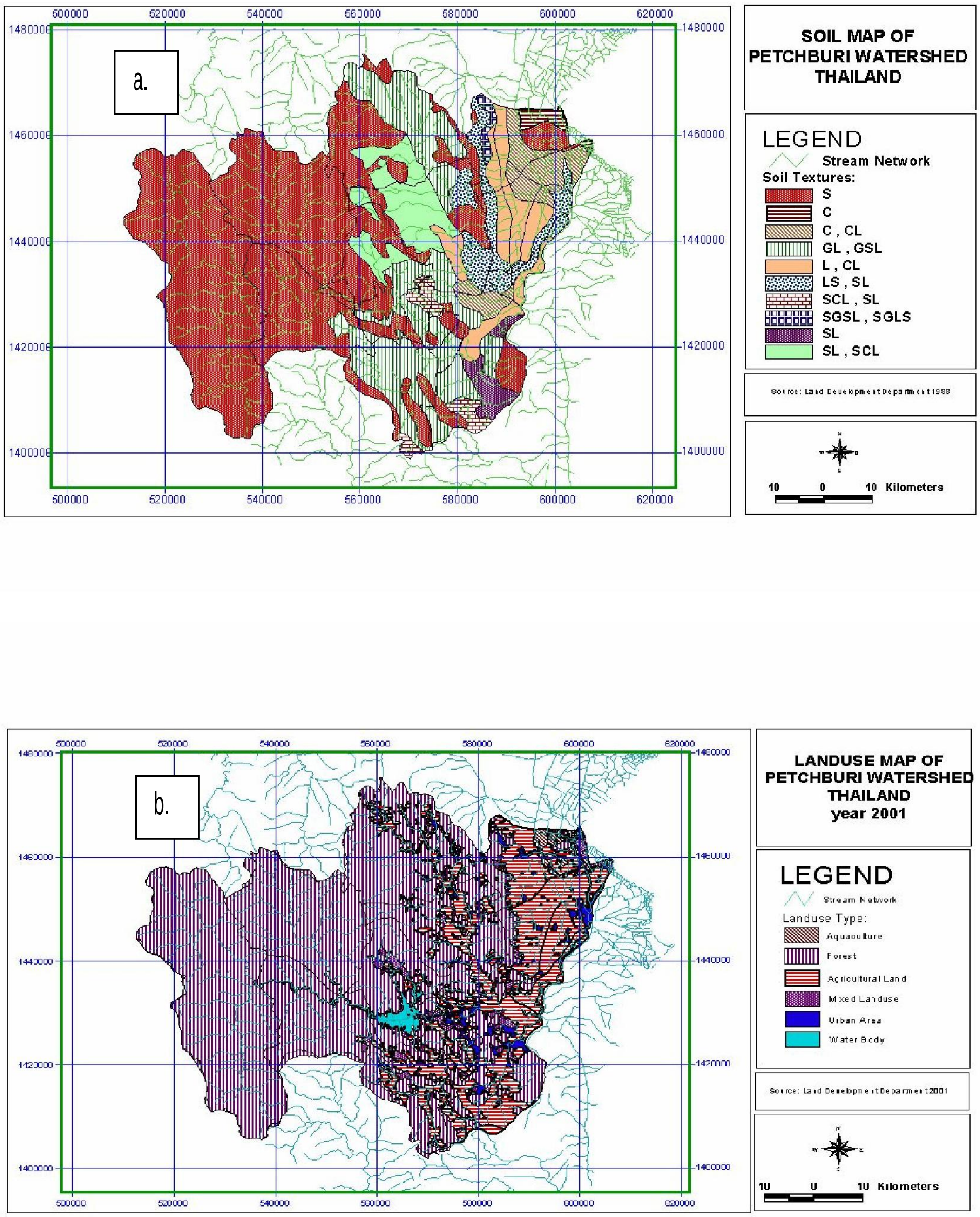


Figure 2. Soil and Landuse Map of Petchburi Watershed

a. Soil Map

b. Landuse Map

Soil texture of the Petchburi Watershed vary from sand at the upstream to clay at the coastal area. As seen in Figure 1 together with Figure 2.a, soil textures of subwatershed 1, 2, and 3 (Bankloi, Mae Pradon, and upper Kaeng Krachan, which are categorized as upstream) are mostly sand (S) to gravelly sandy loam (GSL). From subwatersheds 5 to 14 (Upper Mae Prachan to coastal area), the soil textures vary with compositions of S (sand), SL (sandy loam), SCL (sandy clayey loam), SGSL (sandy gravelly silty loam), SGLS (sandy gravelly loamy silt), GL (gravelly loam), GSL (gravelly sandy loam), LS (loamy sand), L (loam), CL (clayey loam), and C (clay). These soil textures effect the infiltration capacity of the watershed. They were processed using physiographical analysis to be used as one of the CN (Curve Number) components together with the landuse types at each subwatershed.

More than 95% of subwatershed 1, 2, and 3 (upstream) are covered with forest. Overall, landuse types in the Petchburi Watershed are forest, agricultural land, aquaculture, mixed landuse, urban area, and water body. These landuse types with some simplifications, together with the soil textures will determine the curve number of each subwatershed. The landuse Map is shown in Figure 2.b.

The points of phytoplankton and phosphate-P measurements in conjunction with the estimation of water flow in this study were as follows (Figure 1):

Stations P1 to P3 represent the upstream area of the watershed, as lotic (P1 and P2) system and close to lentic (P3) system.

Station P1 - primitive forest area at the headwater, Petchburi River: UTM 47P 1434379 N, 0537046 E

Station P2 - forested and agricultural area at the upstream, Mae Pradon Subwatershed: UTM 47P 1433849 N, 0552970 E

Station P3 – forested and agricultural area at the upstream, Petchburi River: UTM 47P 1427704 N, 0558851 E

Stations P5 to P10 represent the downstream of the watershed, mostly lotic system, although in a hydrologic perspective P10 is in the estuary which has different characteristics than a lotic system. Note: P11 was not assessed because it is not included in the river routing.

Upper downstream:

Station P5 - Petchburi River after (below) Kaeng Krachan Reservoir: UTM 47P 1421131 N, 0577809 E

Station P6 - tributary in the Huay Pak Subwatershed, Petchburi: UTM 47P 1417196 N, 0579646 E

Station P7 - outlet of Mae Prachan Subwatershed, Petchburi: UTM 47P 1429704 N

Lower downstream:

Station P8 - gauged B1A station, Petchburi River: UTM 47P 1446479 N, 0602648 E

Station P9 - domestic and industrial areas, Amphoe Maung, Petchburi Province: UTM 47P 1450564 N, 0603707 E

Station P10 - aquaculture area at the Ban Lam Estuary: UTM 47P 1461741 N, 0607948 E

With the above background, objectives of this article were:

1. To estimate water flow at the point of Various water quality sampling stations,
2. To give a depiction of the event seasonal trend of water flow and phytoplankton biovolume, and
3. To explore water flow data analysis in conjunction with instantaneous water quality measurement in the river.

METHODOLOGY

Data Gathering

Data used in this research came from field research on phytoplankton and some chemical properties of the Petchburi River from December 2001 to October 2002, guided by a collection of base map of Thailand from GIS Thailand. Secondary rainfall and flow (discharge) data at several gauged stations from the Royal Irrigation Department together with the Royal Climatology and Meteorology Department are also gathered.

Laboratory investigation of phosphate-P samples in water was assessed according to the methods described by APHA and WEF[1], Wetzel and Likens[25]; phytoplankton counts were made using a Sedgwich-Rafter counting cell under microscope. The biovolume was calculated by using the Rott method[15]. Map layouts were made with ArcView GIS version 3.3, after digitizing, editing, and tabling areas of the subwatersheds[4].

The stations representing lotic system and availability of data are : P1, P2, P3, P5, P6, P7, P8, P9, and P10. Station P4 was not assessed because it is a full lentic system inside the Kaeng Krachan Reservoir, and a vertical profile is more important. Station P11 was not assessed because of the routing technique: routing toward the estuary by the shortest length was chosen, thus P10 was picked (see Figure 1). If further research on P11 is needed, on site field measurements should be conducted. The river routing for Petchburi watershed was simulated using the WMS (Watershed Modeling System) version 7.0, Public Domain[26].

Data Analysis

A hydrological data-availability concept-model is proposed, which means that the assessment of water flow is approximated in conjunction with the availability of data. A flowchart of the conceptual flow data analysis together with water quality data is shown in Figure 3, with number 2.2.2 as the corresponding method of analysis for this research; Some remarks are discussed in the result and discussions part.

Flood prediction downstream of the Petchburi watershed after the Kaeng Krachan Reservoir, has been analyzed by Sawetprawitchkul.[(17)] In contrast to Sawetprawitchkul's research, the research for this paper is not to estimate flow for flood, but to estimate flow in conjunction with water quality (mainly phytoplankton biovolume) at certain points. Therefore maximum rainfall data is not used. Instead, average rainfall data is used as the input. It is suggested that, due to uncertainty of phytoplankton biovolume at certain discharge points, the flow should be measured at the time of phytoplankton measurement. But due to the absence of flow data at the time of measurement, estimated flow at the points of phytoplankton measurements was used with data available.

In hydrology, models contain free parameters that must be calibrated to a particular situation in which a model is applied.[(2)] There is even a debate as to whether so-called physically based distributed models are in reality lumped conceptual models operating at a grid scale. While much has been learned in a Distributed Model Intercomparison Project (DMIP), few would argue that these and other questions are close to being fully understood and answered.[(19)]

Observed hydrograph from gauged stations will give the better runoff data when compared to synthetic hydrographs which do not origin are at the observation is being conducted. This has been studied by Kharmanto (1993) in the Madiun watershed in Java, Indonesia. This research resulted in a deviation from the of Snyder and Clarke synthetic hydrograph in Java when compared to the observed hydrograph.[(8)] This showed that locality is an important factor in hydrological analysis; thus, empirical and synthetic formulas should be somehow modified to fit to the local situation.

The Petchburi Watershed is divided into 14 subwatersheds for the subwatershed-scale lumped system (Figure 1). The approach was to estimate flow which occurred in the river or tributary (stream) in conjunction with water quality data. This approach takes into account the landuse of each subwatershed which is mainly divided into 4 categories: forest, agricultural, urban, and mixed landuse.

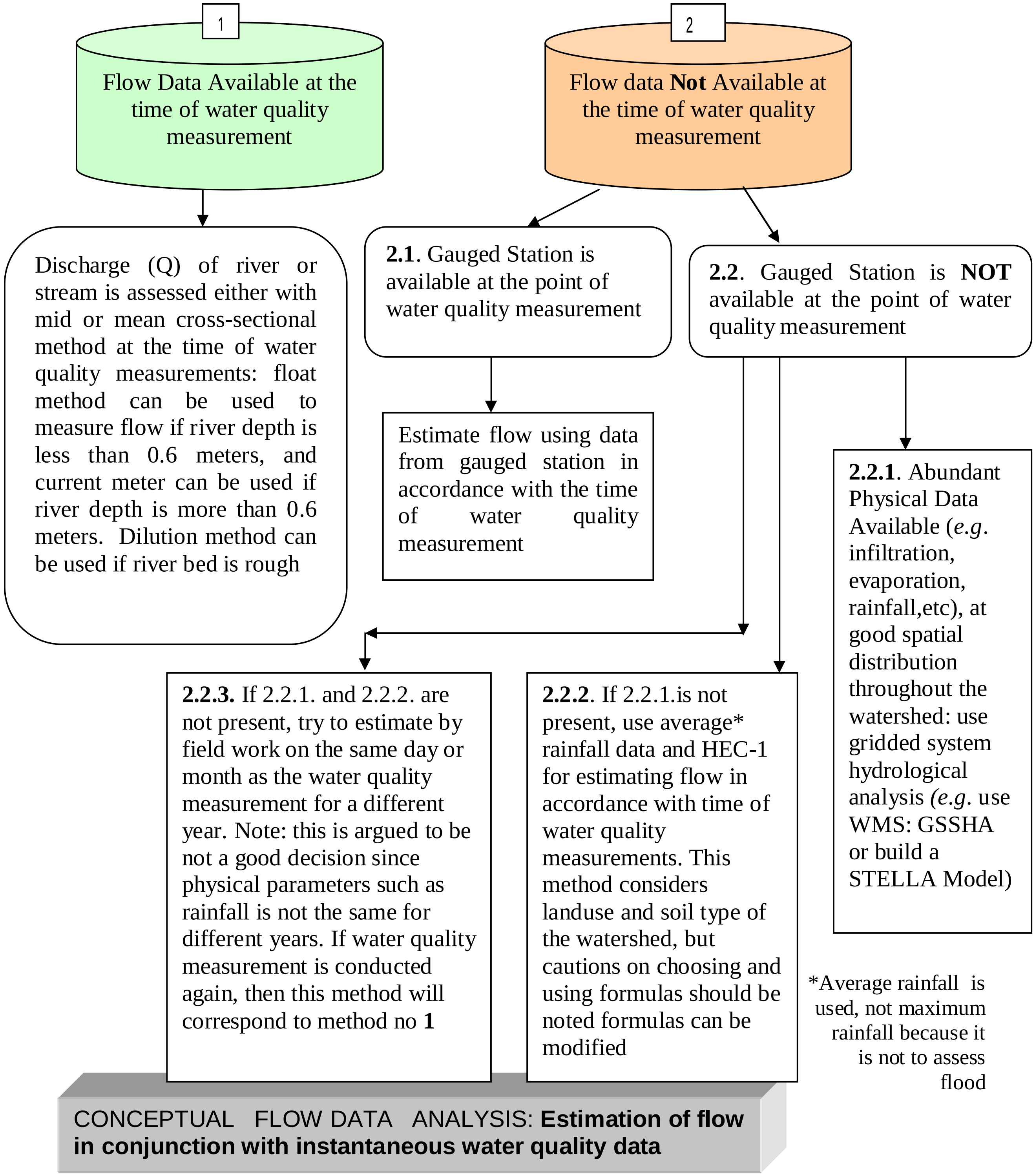


Figure 3. Flowchart of Conceptual Flow Data Analysis in Conjunction with Water Quality Data.

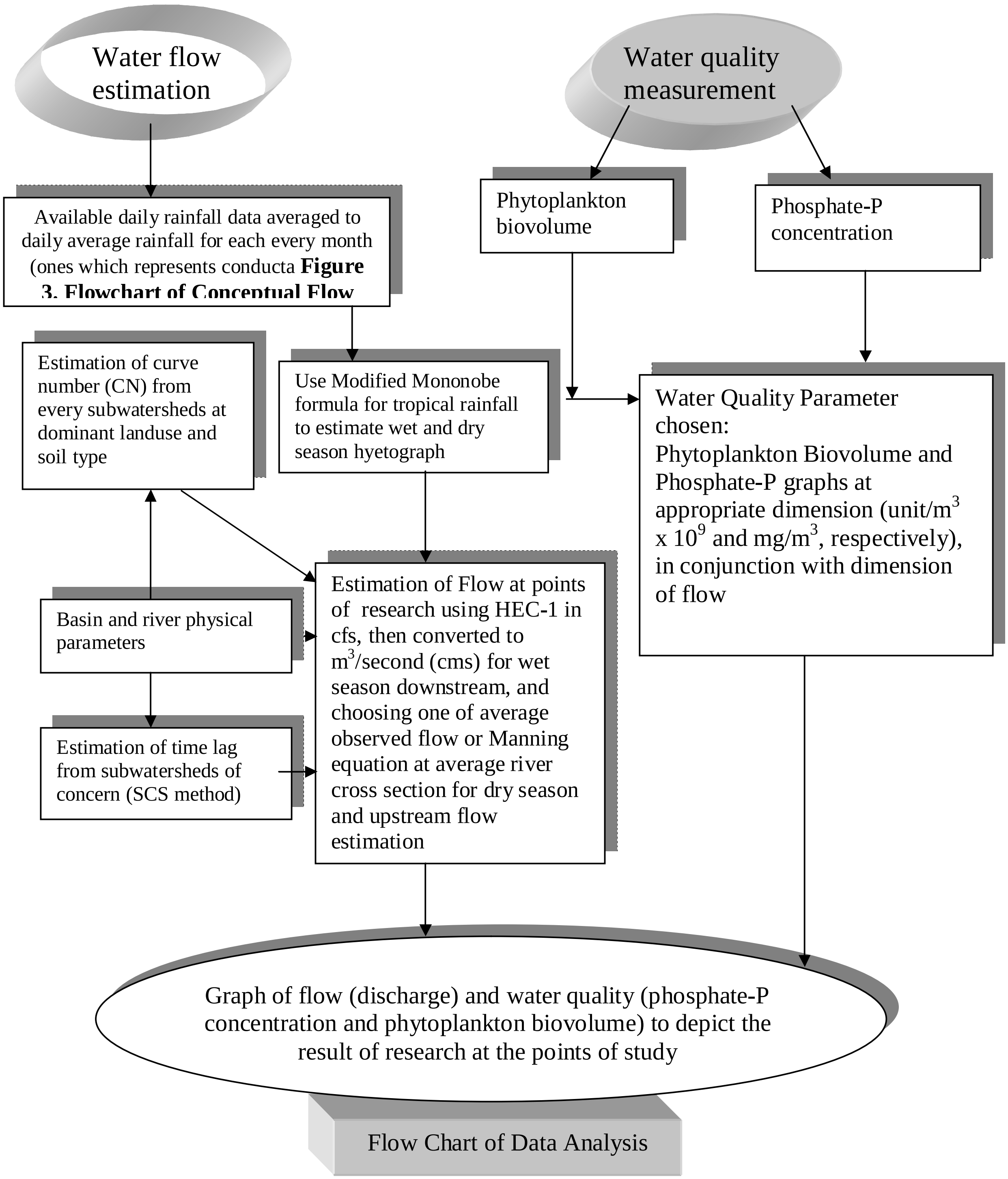


Figure 4. Flow Chart of Petchburi Watershed Analysis.

Soil types were also taken into consideration. A process – based - physical hydrology approach can be conducted for further research when the physical parameters are available. Figure 4 shows the flowchart of the Petchburi Watershed Analysis. The hydrologic abstraction was conducted using the runoff curve number method. The runoff curve number method is a procedure for hydrologic abstraction developed by the United States Department of Agriculture (USDA), Soil Conservation Services (SCS).(13) In this method, runoff depth is a function of total rainfall depth and an abstraction parameter referred to as the runoff curve number, curve number, or CN. The CN varies in the range of 1 to 100, being a function of the following runoff-producing catchment properties: hydrologic soil type, landuse and treatment, ground surface condition, and antecedent soil moisture condition.(13) The USDA SCS has instituted a soil classification system for use in soil survey maps across the country. Based on experimentation and experience, the agency has been able to relate the drainage characteristics of soil groups to a curve number, CN. The soil and landuse map layouts used for estimating CN for Petchburi Watershed is shown in Figure 2. The runoff curve number was based on 24-h rainfall-runoff data. The temporal rainfall distribution used in this research is Mononobe's rainfall distribution for tropical rainfall, with modification to match with the output of flow at the gauged stations with reasonable CN range, therefore it is named the Modified Mononobe's Intensity formula. Since it is calibrated only at the Petchburi Watershed, it is called PetMMI (Petchburi Modified Mononobe Intensity) formula.

The SCS synthetic unit hydrograph was used to estimate flow in this research. This hydrograph was developed based on the analysis of a large number of natural unit hydrographs from a wide range of catchment sizes and geographic locations. This method has come to be recognized as the SCS synthetic unit hydrograph and has been applied to midsize catchments (100 to 5000 sq.km) throughout the world[13].

Afterwards, river routing was conducted by the Muskingum Cunge Method. The advantages of this method over other hydrologic techniques are: (1) the parameters of the model are physically based, (2) the method has been shown to compare well against the full unsteady flow equations over a wide range of flow situations(7,13) and (3) the solution is independent of the user specified computation interval.(7) The major limitations of the Muskingum-Cunge application in HEC-1 are that: (1) it can not account for backwater effects, and the method begins to diverge from the full unsteady flow solution when very rapidly rising hydrographs are routed to very flat slopes (i.e. channel slopes less than 1 ft/mile).(70 Data for the Muskingum-Cunge method consist of the following for either a main or collector channel:

1) Representative channel cross section
2) Reach length, L
3) Manning roughness coefficients, n
4) Channel bed slope

For some small streams, it may be very difficult to obtain good estimates of the average depth of the water because of alternating pools and riffles. The flow, however, may be known from a downstream gauging station. Further, the width of most streams does not vary nearly as much as the depth. Thus, a stream may have highly variable depth, but the flow and average width can be obtained.(20) Estimates of stream velocity can be obtained from the empirical open channel equation developed by Manning in 1890, commonly referred to as the Manning equation.

$$v = 1/n\ (R^{2/3})\ (S^{1/2})$$

where v is the flow velocity in m/s, R is the hydraulic radius, n is the Manning roughness coefficient and S is the stream slope.

This equation is limited to small slopes (under 10%), steady flow, and reasonably long, straight reaches where the bed slope is constant. The discharge of the stream or river cross section is estimated by multiplying the velocity with the average width of the river, which in this research is assumed to be close to a trapezium shape.

RESULT AND DISCUSSIONS

Flow (Discharge)

Figure 5 shows the output of Routed WMS Petchburi Watershed downstream, estimated for October 2002 (wet season from B3 or point 10C to P10 or point 1C). In addition, in Figure 5.a: routed P6, which is part of subwatershed 10, to estimate flow in the tributary (stream), because P6 water quality station is not located in the main stream. All estimated flow of Figure 5.b are routed starting from B3 (below Kaeng Krachan Reservoir) using high CN. The flow is calibrated with adjusted CN to match the gauged stations. All are in the range of high CN of the U.S. SCS, except for CP2 from subwatershed 11 and B1A from subwatershed 12 which calibrated above the high CN. This can be caused by several factors:

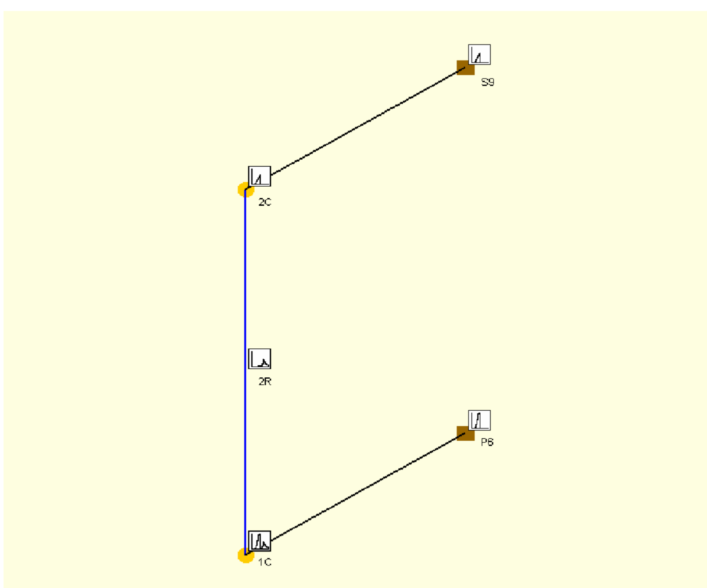
1) CN is primarily based on U.S. experimental data and in general it is determined from landuse and soil maps;
2) More detailed maps are needed, especially for the estuary or it can be better assessed using professional WMS and more detailed DEM to better assess the basin and river parameters, including the exisance of the small dam near CP2.
3) Rainfall can be better assessed with more accurate and more widely distributed data.

Hhydrologic assessment results by other scientists note thas for the majority of basins, lumped models showed better overall performance than distributed models. However in some cases were the oppose held true.(14) This can be a result of how hydrologic models are constructed under different conditions of data availability. Topography also influences the rainfall-runoff output, and watershed hydrology is mostly driven by site-based parameters.(5)

Different data sources for precipitation yield different results for the water budget.(6) Sufficiently fine rainfall measurements are an important factor to perform useful hydrologic analysis. The influence of the spatial distribution of rainfall must be considered. Brath (2004) found that model performance does not seem to noticeably deteriorate assuming spatially uniform rainfall, provided that the mean areal rainfall intensity is reliably estimated on the basis of a sufficiently extensive number of raingauges.(3)

In forested basin catchments infiltration by excess overland flow is most unlikely to occur. Evidence of overland flow is most likely to result from a saturation excess mechanism.(2) Therefore, routed excess rainfall in Petchburi Watershed is performed in the wet season only (starting from B3 from subwatershed S1234 to P10). For upstream flow, assessment is based on the average measurements and the Manning equation.

The complete estimation of flow assessment is shown in Table 1. It is seen that at P5 flow is reduced due to the effect of a reservoir upstream. When more physical distributed data are available, correction of the estimated faFGJT5low upstream can be made. This area has steep hillslopes and almost no standing water, and flow pattern for the unit model and its spatial implementation should take into account vertical fluxes.(24) From the flow analysis using WMS version 7.0 and other suitable hydrologic formula we observed the wet season flow in each station was higher than that of the dry season, which is as expected. The more important fact to be discussed is the depiction of the characteristic of flow in conjunction to water quality, and also CN which can be seen from Figures 6 and 7.



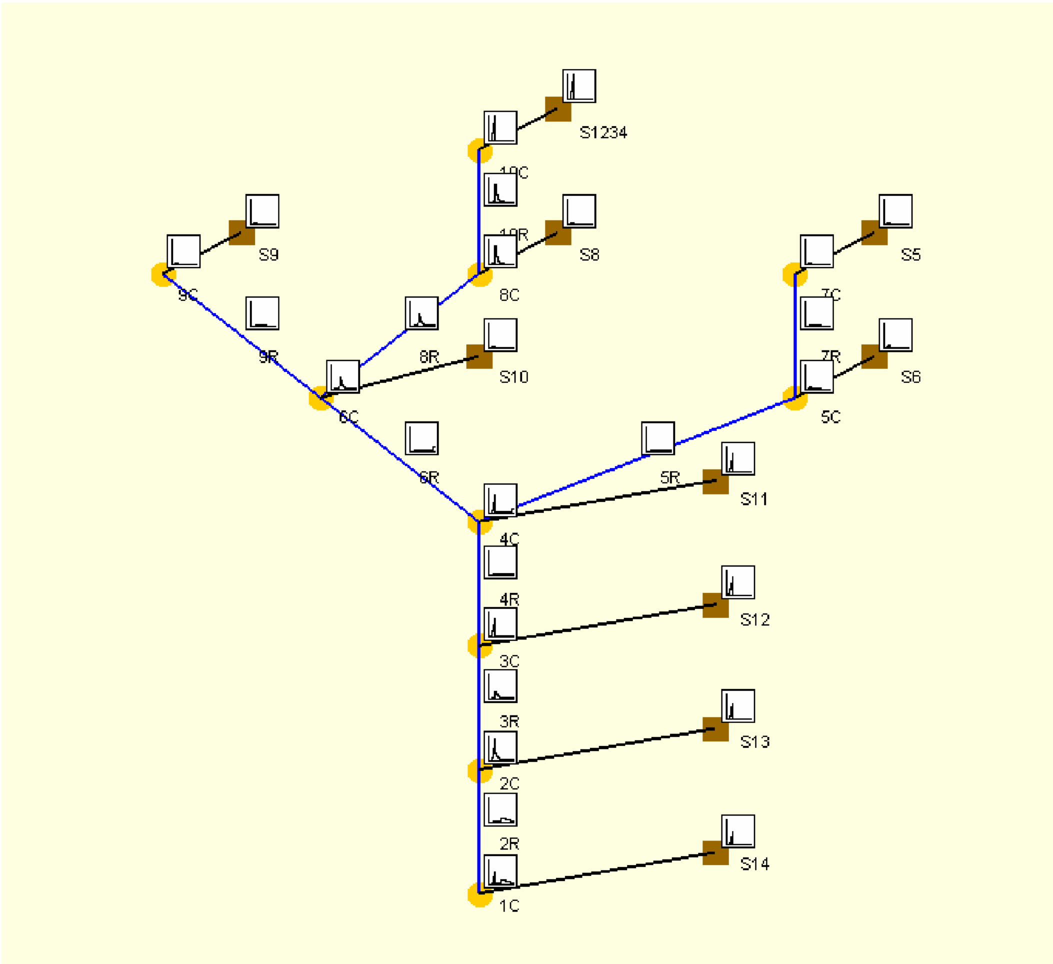


Figure 5. Output of Routed WMS Petchburi Watershed for October 2002 (wet season).

Table 1. Estimated Flow and Measured Phytoplankton Biovolume in Petchburi Watershed, Thailand at Points of Water Quality Station.

Assessment	Season	Water Quality Station								
		Upstream			Downstream					
		P1	P2	P3	P5	P6	P7	P8	P9	P10
Water Flow (cms)	Dry	14.55	24.70	14.62	29.32	1.66	3.31	34.03	37.48	26.23
	Wet	118.13	102.43	199.93	51.5	1.74	8.43	50.37	59.02	31.29
Phytoplankton Biovolume (unit/m^3 x 10^9)	Dry	4.89	6.15	7.54	5.63	3.88	1.09	1.10	2.69	1.09
	Wet	0.31	0.03	945.05	24.62	6.58	4.52	0.88	4.4	573.21
Corresponding Month		Feb Aug	Feb Aug	Feb Aug	Dec Oct	Dec Oct	Dec Oct	Dec Oct	Dec Oct	Dec Oct
Comments		Dry: *** Wet: ***	Dry: *** Wet: *	Dry: **** Wet: ****	Dry: * Wet: **	Dry: * Wet : **	Dry :* Wet : **	Dry: * Wet: ****	Dry: * Wet: **	Dry: * Wet: **

* is flow estimation using the Manning equation at an average width of river or stream crossection at the corresponding month
** is flow estimation using WMS public domain with PetMMI rainfall distribution, SCS unit hydrograph method and Muskingum-Cunge routing
*** is flow estimation using Chadnaree Meesukko average field measurement
**** is flow from gauged station

Phosphate-P Concentration and Effect of Soil and Landuse Pattern (CN)

Under certain conditions phosphorous may be the limiting nutrient in the river[(20)] That is why phosphate-P (phosphate–phosphorous) is important. It is shown in Figure 6 that the value of phosphate-P in general was low upstream (P1, P2, P3) in the dry season. Then the concentration increased in the wet season because of high sediment loading from the land.

The phosphate-P value at station P1 was low in all seasons (below 15 mg/m^3). This is because station P1 is located in the primitive forest (undeveloped subwatershed) at the head water of the watershed. In addition, phosphate–P concentration is very low in the natural surface water of rivers[25]. That means that it is low when there are no additional sources of phosphorous such as from fertilizers.

At station P2, the government permits fertilizers for agriculture. This is the probable cause of the increased levels (more than 20 mg/m^3) of phosphate–P concentration in the wet season at station P2. This increasing level can be seen more clearly by assessing phosphate-P further downstream (Figure 7).

Downstream characteristics of flow were different from the characteristics of upstream flow, especially at the estuary. The highest concentration is around 126.52 mg/m^3 at station P10 at the beginning of the dry season (December 2001). Stations P5, P6, P7 (upper downstram area, see Figure 1) which are less developed than P8, P9, P10, have lower phosphate-P concentration in dry season; while P8, P9, P10 have higher phosphate-P concentration in dry season. In the dry season, the flow of water in the river decreased, while the wastewater from households and agricultural areas downstream were still occurring. This which would increase phosphate–P concentration.

Landuse patterns and soil type in connection with CN also can further explain the difference between phosphate-P concentrations in the river upstream and downstream. In upstream or forested (undeveloped) subwatersheds, CN are low (60.7) which means that runoff to the river was lower, thus the amount of nutrients transported to the river in all seasons would be smaller in value than that in the downstream subwatersheds. For upstream concentration itself, in dry season, due to the good self-purifying characteristics in the undeveloped subwatersheds, river flow is from baseflow only and the natural river water quality was found to be better (no or little nutrients). This is why, for upstream watershed, phosphate-P concentration is higher in the wet season when there is some runoff which carries nutrients to the river. Also for the upper downstream (P5 to P7), CNs were below 85.

Contrary to the upstream flow characteristics, downstream CN (P8, P9, P10) were high (above 90). This was caused by the developed subwatershed. Agricultural land, urban development, and mixed landuse are faesent more than alting upper downstream and upstream locations. Low infiltrating capacity of soil, which means that, although the river flows in the dry season only come from baseflows, the self purifying of the developed subwatersheds is not as good as that in the upstream regions. Moreover, we believe, that because of the urban and agricultural areas, domestic waste and agricultural waste are loaded throughout the year. This will lead to high nutrient levels in the dry season when the flow and volume of river water are lower than in the wet season.

Phytoplankton Biovolume

For station P1 (the primitive forest area at the head water, Petchburi River), phytoplankton biovolume was low (Figure 6) because the high velocity of the stream is not suitable for phytoplankton growth (Table 1). At station P2, average phytoplankton biovolume was higher than that of station P1 (7.53 x 10^9 unit/m^3 and 5.10 x 10^9 unit/m^3 respectively). Although P2 is also located upstream, it has an agricultural area along the river banks which contributes to higher nutrient loading. However, in August 2002 it was raining heavily, thus phytoplankton biovolume was lower than anticpated.

At station P3 (agricultural area at headwater, Petchburi River), phytoplankton biovolume increased compared to station P1. Station P3 has the ecological conditions close to a lentic ecosystem because it is located at the inlet of Kaeng Krachan Reservoir and there is a phytoplankton bloom throughout the wet season. In addition, the water washed nutrients down from the upstream agricultural areas along the river banks. This was favorable for phytoplankton growth, especially during the wet season. This finding was similar to the study in Kaeng Krachan Reservoir where the phytoplankton biovolume increased in the wet season because the water inflow and rainfall delivered organic matter and nutrients from the watershed into the reservoir.[9]

In downstream sites, phytoplankton biovolume at P5 to P9 were lower than phytoplankton biovolume at P10 (estuary). There was phytoplankton bloom in the wet season in the estuary (Table 1, Figure 7).

From the results of this research, it is apparent that there is a difference in the Phytoplankton biovolumes depending on the characteristics of flow. Wet season phytoplankton biovolumes for lentic or close to lentic systems such as at P3 (input to Kaeng Krachan Reservoir, 945.05 x 10^9 unit/m^3) and P10 (estuary, 573.21 x 10^9 unit/m^3) are higher than those of the dry season (7.54 x 10^9 unit/m^3 and 1.09 x 10^9 unit/m^3 respectively), while dry season phytoplankton biovolumes for some lotic (river) system Points (P1, 4.89 x 10^9 unit/m^3; P2, 6.15 x 10^9 unit/m^3; and P8, 1.10 x 10^9 unit/m^3) are higher than those of the wet season (0.31 x 10^9 unit/m^3, 0.03 x 10^9 unit/m^3, 0.88 x 10^9 unit/m^3 respectively).

Discussion on Validation

Although complete validation for models of natural systems is hardly possible because of their open systems[11] under certain specified performance conditions they can be judged and ranked[16]. Validation means that a model is acceptable for its intended use, because it meets specified performance requirements. Variation in the amount of data available and the level of understanding of the system influences the types of validation tests that can be conducted.[16]

Rykiel (1996) proposed 4 classes of modeling problems in relation to available data and understanding for validation:

1) Explanatory/Theoretical Model Development: face and event validity; conceptual validation is relevant.
2) Conceptual Model Validity: comparison to other models, face validity, event validity, turing test, traces; qualitative validation is relevant.
3) Data Validity: statistical model validity; statistical validation is relevant, which is conducted when data is increasing
4) Conceptual Model Validity, Data Validity, Operational Validity: all validation techniques; quantitative validation is relevant, which can be conducted if data and understanding of the system are increasing.

The Petchburi Watershed analysis is in the explanatory type of validation, for the downstream October 2002 result, where the input and output result of the flow is reasonable for face and event validity shown in Table 2. Phytoplankton biovolume is from onsite measurement, so it is valid as it is in Table 1. The other result cannot yet be validated. Recommendation of the hydrological-biological alternative assessment is shown in Table 3.

Conceptual or physically based, process based-distributed hydrologic model can be further research alternatives to better estimate hydrological output when more data are available.[14, 22, 23, 24]

CONCLUSION

The trend of flow analysis using WMS v.7.0 public domain and other relevant hydrologic formulas showed that upstream to downstream flows for dry season are always lower than those of wet season, and the type of subwatershed (developed or undeveloped, which is also depicted by the curve number, CN) gave different results to the runoff of the river.

There are considerable differences in the water quality, depending on the characteristics of flow. Wet season phytoplankton biovolumes for lentic or close to lentic system such as at P3 (input to Kaeng Krachan Reservoir) and P10 (estuary) are higher than those of the dry season, while dry season phytoplankton biovolumes for some lotic (river) systems (P1, P2, P8) are higher than those of the wet season. Phosphate-P concentrations in the river show that they are generally higher in developed subwatersheds and are lower in undeveloped (forested) one shave with higher concentration downstream in dry season when flow is low.

Detailed analysis for a good and validated flow assessment is preferable, but for certain conditions a preliminary estimation can be useful to know the trend of water flow in conjunction with water quality data, especially with restricted budget and time. Table 3 is a recommended alternative of flow assessment in term of data availability and time.

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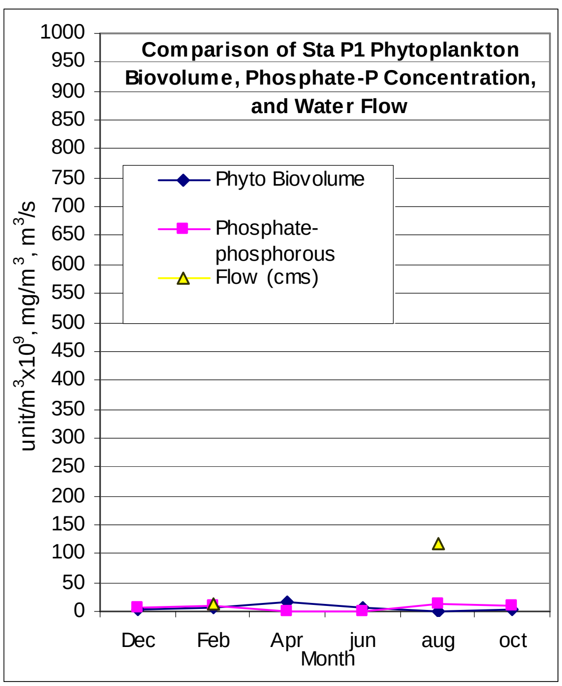
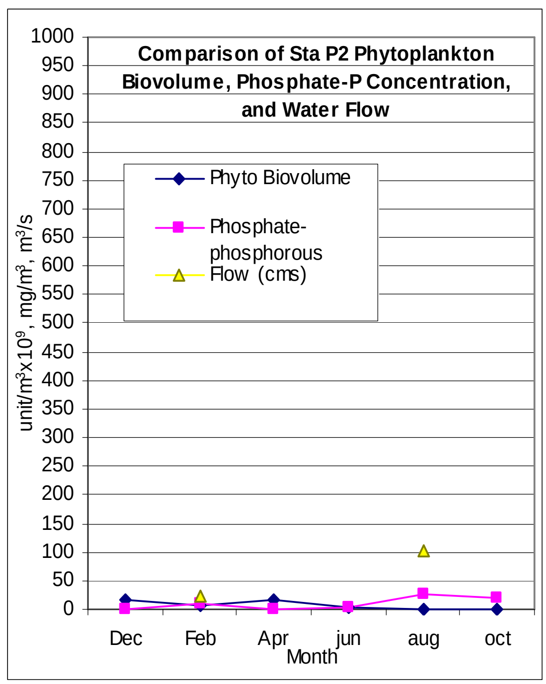




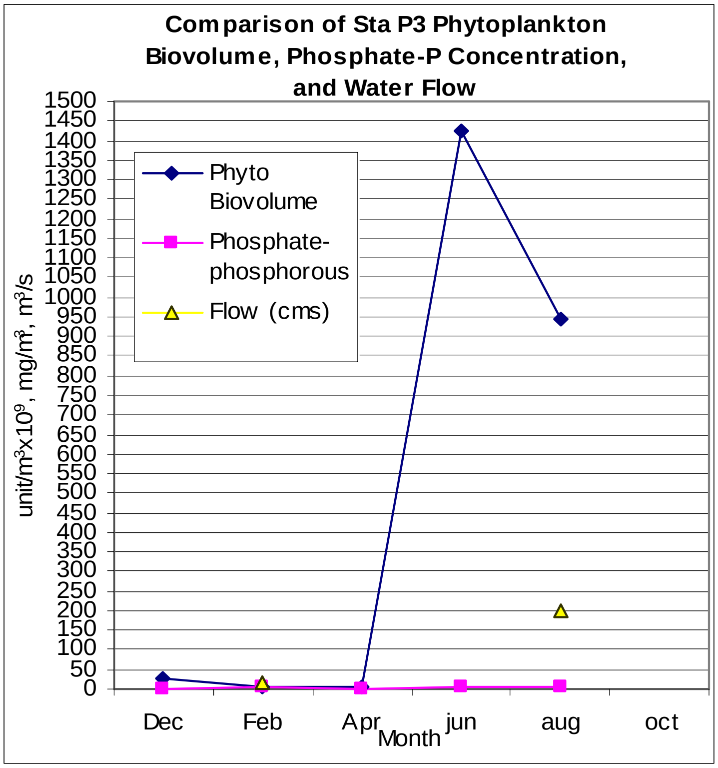
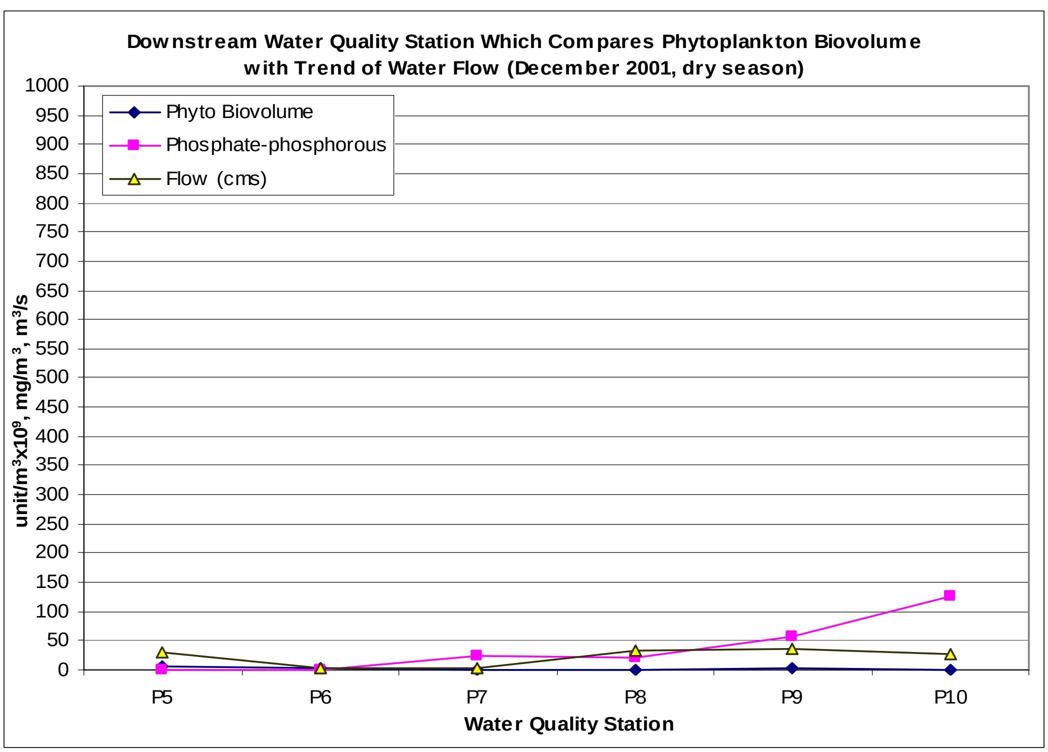


Figure 6. Graph of Upstream Estimated Flow- Phytoplankton Biovolume.



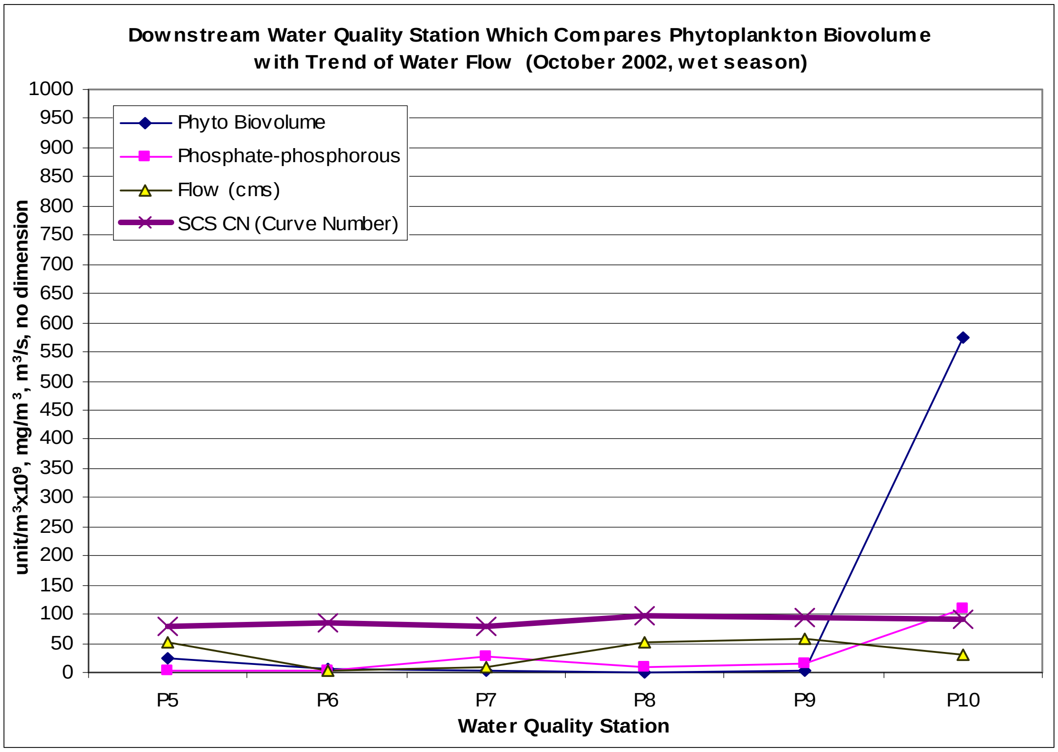


Figure 7. Graph of Downstream Trend of Flow in Conjunction with Phytoplankton .Biovolume.

Table 2. Face and Event Validation on October 2002 (Wet Season) Flow at Gauged Stations.

Stations	Discharge (Q)				Remark	difference	% difference
	October, in cfs		October, in cms				
	observed	simulated	observed	simulated			
B1A (P8)	1790.57	1778.39	50.71	50.37	Ok	0.345	0.000068
B8 (HuaiPak)	34.60	36	0.98	1.02	Ok	0.040	0.000403
B6 (P7)	290.60	297.60	8.23	8.43	Ok	0.198	0.000241
B3 (S12347)	2560.33	2521.58	72.51	71.41	Ok	1.097	0.000151
Difference tolerance is 0.001 (0.1%)							

Table 3. Alternatives on Hydrological-Biological Data Analysis in Term of Data Availability.

No	Data Availability	Suggested Assessment	Duration of Research and Fund	Remark
1	• Water quality (chemical, biological) only at several points in the watershed • Flow only at several gauged stations, not all at water quality station, from departments, no distributed data • Rainfall at some places in the watershed	To assess flow in conjunction with water quality data, use lumped estimation at subwatershed scale (it was called distributed data analysis if the view was from watershed scale (Ponce, 1989), but due to more advanced technology to assess more detailed physical data if data are available, lumped system at subwatershed scale is chosen as the name of this type of analysis)	• 3 months to 1 year of research • no additional fund needed if water quality data is available	Conceptual validation only (face and or event)[16] at several relevant places (i.e. the gauged stations), cannot be quantitatively validated
2	• Some physical, chemical and biological data (rainfall, flow, chemical properties in atmosphere-soil-water, biological properties) available at a subwatershed scale at the same time of measurement	Rough estimation on physical-based ecological dynamic modeling at subwatershed scale, Can be compared to the alternative no.1 in term of flow and water quality at relevant points	• 2 to 3 year research • medium fund	Qualitative validation at the outlet of each subwatershed, cannot be quantitatively validated
3	• Detailed physical (including good spatial distribution of raingauge stations), chemical, and biological data available at grid scale, or at least at different landuse and soil types, continuously	Distributed physical based ecological dynamic assessment	• 3 to 5 year research • large fund	Quantitative validation available