ABSTRACT

THE APPLICATION OF MATHEMATICAL MODELS FOR AN ENVIRONMENTAL FLOW ASSESSMENT AND TOTAL MAXIMUM DAILY LOAD (TMDL) OF PRACHINBURI–BANGPAKONG RIVER

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This research assessed the environmental water demand and Total Maximum Daily Load (TMDL) of Prachinburi-Bangpakong River, Thailand. This was done by applying the mathematical models in order to study Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD), assess the TMDL in the form of pollutants that had BOD, and evaluate Environmental Flows (EF) or minimum demand of water reservation, respectively.

The studied river was selected distances of 146 km inland freshwater and was divided into five reaches which based on the Water Quality Monitoring Station of the Pollution Control Department. Research results using the mathematical models indicated that in studying the water quality of the river during 1996-2006, the mean of DO was between 4.9 - 6.8 mg/L and the mean of BOD was between 1.7 - 2.1 mg/L. Furthermore, the assessment of the TMDL in the form of BOD found that the mean of the TMDL in real condition was between 33.5 - 109.9 kg/d and the mean of the TMDL in Class 3 condition was between 43.9 - 506.5 kg/d. Environmental Flows Assessment found that the mean of the water flow in real condition was between 7.6 - 11.7 m^3/s and the mean of the water flow in Class 3 condition was between 10 - 53.9 m^3/s. This identified condition will enable better water quality and carrying capacity of the river. Therefore, the water flow in Class 3 condition was limited to EF, which was the minimum demand of water reservation in this river.

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1. INTRODUCTION

Environmental flow assessment (EF) or Environmental Water Demand, which is minimum demand of water reservation in order to maintain natural balance of rivers. Amount of water affects its water quality as a result of self-purification of river. Although the nature has ability to maintain its balance and self-recovery, it still has limitations only at a certain level. Changed ecosystem affects living creatures in the water and the users in terms of economics and society. At present, there are not techniques and methods to assess appropriate quantity or level for water need. Therefore, there should be a study to specify Threshold Level of water need by using appropriate techniques and methods (Bhaktikul, 2007).

This research aims to study the assessment of Environmental Flows to specify the lowest flow level to maintain water ecology by using mathematical model of Total Maximum Daily Load (TMDL) in the form of pollutant that has Biochemical Oxygen Demand (BOD). This research applies TMDL models, which can explain the quantity of pollutants release to water or flow to water resource (Lung, 2001). The relationship of self-purification processes and oxygen balance occurred in the river can be used to calculate change. First, the river will be divided into the ranges by considering position of the Water Quality Monitoring Station of the Pollution Control Department. Then the raw data will be calculated and arranged in the form of variables for forecast, including water flow of the river (Qr), flow of wastewater (Qw), BOD Load, Reaeration Coefficient (Ka), water quality parameters (BOD, DO) by using Streeter-Phelps Model and Mixing Zone Model, Deoxygenation Rate (Dr), Reaeration rate (Rr), Solubility of Oxygen (Cs), DO Deficit (Dc) and Oxygen Balance (Rr - Dr), respectively. After, they will be taken into TMDL model. This result is the value TMDL in real condition as kilograms/day. Next, TMDL model will be improved conditions for forecast the new value TMDL which is the maximum amount of a pollutant that a river can receive and still meet water quality standards. Finally, EF Assessment can converts or back calculates in TMDL model with the experiment as Trial and Error Method. The value EF as cubic meters/second can be applied to the sustainable development of water resource. By the way, this research selects Prachinburi-Bangpakong River as the study area due to the problem of water pollution. It is unable to sustain its balance and corrupts due to highly contamination of pollutants. The study results are not just advice or recommendation only, but an alternation for real and simple future use of everybody. It will be the values that suit the guideline for water management and preservation. However, researchers expect that the value EF is possible to assess by using other method so that it will support the study results each other.

2. ENVIRONMENTAL FLOW (EF)

Environmental Flow is the way to maintain natural water in ecological system. It is the way to manage water to be in appropriate with other usages (Bhaktikul, 2007). There are some words with the same definitions and meanings of EF, such as minimum flow, in stream flow and ecological flow. However, those meanings are still under the same concept as Environmental Flow. The EF can be applied into the entire system of sustainable water resource management which refers to water demand of the ecosystem (King, 2007). Minimum demand of water reservation in the river will contribute to good water quality that is suitable for utilizations.

3. TOTAL MAXIMUM DAILY LOAD (TMDL)

Definition by U.S. Environmental Protection Agency (2002): 'A TMDL or Total Maximum Daily Load is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources.' A TMDL is the sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources. The calculation must include a margin of safety to ensure that the water body can be used for the purposes the State has designated. The calculation must also account for seasonal variation in water quality. In case of organic pollutants (Karnchanawong, 1989), they are dissolved in water and decomposed by Aerobic Bacteria which makes the quantity of organic pollutants vary with the quantity of used Oxygen, i.e. the more the quantity of organic pollutants, the less the quantity of Oxygen in water. The quantity of Oxygen is lessened until the quantity of pollutants released to water is more than water can keep and they change the water quality to be too dangerous to living things in water or higher than the criteria of standard of water usage. TMDL can explain the quantity of pollutants released to water or flowed to water resource (Lung, 2001).

4. METHODOLOGY

4.1 The Study Area

Identification of the study area followed The Department of Pollution Control (1999), which suggested criteria for consideration of the selection of the river reaches in constructing the model in consistency to research objectives, water quality, water content, water flow rate, and location of pollution sources, which had the components of the division of the river reaches as follows.

(1) There was the change of the Water Quality Index (WQI) that was clearly seen in specific period, especially concentration value of BOD, which was primarily used in the river reaches.
(2) The river reaches would be divided before reaching the point of confluence of sub-rivers that was the point of releasing pollution from the source on the watershed sub-areas.
(3) The river reaches would start before reaching the community site that was the source of pollution, leading to the change in water quality in that range and the length was combined along the lowest reaches before reaching other sources of pollution that led to another change in water quality.
(4) The river reaches could be divided based on water utilization activity that could be clearly identified in a certain range.

4.2 Data Collection

Most of the data used in analysis were secondary data collected from governmental sector in the form of statistical database during 1996-2006, including Data in background of Prachinburi-Bangpakong River, Data in hydrology of the Thai Meteorological Department, Data in runoff water of the Royal Irrigation Department, Data in water quality of the Pollution Control Department, Data in land usage of the Land Development Department, Data in population of the Department of Provincial Administration, Data in industrial wastewater of the Department of Industrial Works, Data in livestock of the Department of Livestock Development and Data in aquaculture of the Department of Fisheries.

4.3 Flow Assessment of River

The study of environmental flow required monthly environmental flow data of each station that were measured by the Royal Irrigation Department whereby the study could be from the model of the Mass Balance as follows:

$$Q = Q_r + Q_w \quad \ldots\ldots\ldots\ldots\ldots\mathbf{(1)}$$

where: Q = Total flow rate (m^3/s)
$Q\,r$ = Water flow of river (m^3/s)
$Q\,w$ = Flow rate of wastewater (m^3/s)

4.4 Evaluation of organic pollutant measured in the form of BOD

The amount of pollutant that was measure per unit of the source was called "Population Equivalence", but if it was the total amount of pollutant accumulation, it was called "Loading", as shown in Equation 2 and 3 (The Department of Industrial Works, 2002). This research estimated BOD Loads from the source of water pollution, including domestic wastewater, industrial wastewater and Agricultural Pollutants.

Population Equivalence (g/d/source) = Concentration of pollutant in the water (g/m^3) x Amount of wastewater per source (m^3/d/source) .....**(2)**

Loading (g/d) = Concentration of pollutant in the water (g/m^3) x Amount of wastewater (m^3/d) .....**(3)**

4.5 Reaeration coefficient (Ka)

Reaeration coefficient (Ka) was the function of current speed, temperature, depth, and physical characteristic of the river. In foreign countries, there were researchers who studied and suggested calculation method in many formulas, for examples, Owens et al. (1964), Churchill et al. (1962), O'Conner and Dobbins (1956) by using general equation as follows:

$$Ka = a\left(\frac{v^b}{h^c}\right) \quad \textit{at temperature } 20°c \quad \ldots\ldots\ldots\ldots\ldots\mathbf{(4)}$$

where: Ka = Reaeration coefficient (d^{-1})
v = Average velocity of the reach (m/s)
h = Average depth of the reach (m.)
a, b, c = Constant

The temperature of each area was different, which was the major variable affecting the change of K because many of biochemical procedures depended on temperature; therefore, it required the adjustment of Ka at the temperature of T (Ratanachai, 1996) as follows:

$$Ka_t = Ka\theta^{(t-20)} \quad \ldots\ldots\ldots\ldots\ldots\mathbf{(5)}$$

where: Ka = Reaeration coefficient (d^{-1})
Ka_t = Reaeration coefficient at any temperature (d^{-1})
t = temperature ($°c$)
θ = 1.024

4.6 Water Quality Assessment

The assessment of concentration of BOD after the drainage of wastewater into the water sources could apply the model called "Mixing Zone Model," which was the mathematical model used for immediate evaluation of water quality after drainage, as demonstrated in Equation (6)

$$L_o = \frac{(C_w Q_w + C_r Q_r)}{Q_w + Q_r} \qquad \text{...............}\mathbf{(6)}$$

where:

L_o	=	Remaining BOD at time t = 0 (mg/L)
C_w	=	Concentration of pollutant in wastewater (mg/L)
Q_w	=	Flow rate of wastewater (m^3/s)
C_r	=	Concentration of pollutant in the river prior to wastewater loading (mg/L)
Q_r	=	Water flows in the river prior to wastewater loading (m^3/s)

The change in BOD that was measured at different points was the function of distance, which could be obtained from the equation. The formula used to explain the phenomenon from insertion of BOD into the river was the equation of Streeter – Phelps (1995) as follows:

$$-\frac{dL_t}{dt} = K_b L_t \qquad \text{...............}\mathbf{(7)}$$

where:

L_t	=	Remaining BOD at time t = t (mg/L)
t	=	time (day)
K_b	=	Coefficient of organic substances decomposition (d^{-1})

When integrated Equation (5) from t = 0 to any t, the equation would be as follows:

$$L_t = L_o e^{-Kbt} \qquad \text{...............}\mathbf{(8)}$$

where:

L_t	=	Remaining BOD at time t = t (mg/L)
L_o	=	Remaining BOD at time t = 0 (mg/L)
e	=	2.7183
Kb	=	Coefficient of organic substances decomposition (d^{-1})
t	=	time (day)

Dissolved oxygen would be used in organic decomposition to reduce concentration until the value was lower than Equilibrium DO concentration; as a result, there was the transfer between water and air. Oxygen feed was a direct proportion to DO deficit in which some rivers would have a high level of photosynthesis of seaweed (Arunlertaree, 2003). Therefore, dissolved oxygen from photosynthesis was greater than from the atmosphere. However, this research did not consider the change in dissolved oxygen obtained from photosynthesis as information on photosynthesis rate of seaweed was absent. Generally, the oxygen feed procedure would occur simultaneously with the procedure of oxygen usage. As a result, the concentration of dissolved oxygen was equivalent to the difference between oxygen usage and oxygen feed (Ratanachai, 1996), as shown in Equation (9).

$$\frac{dD_c}{dt} = K_b L_t - K_a D_c \qquad \text{...............}\mathbf{(9)}$$

where:

D_c	=	Concentration of DO deficit that was equivalent to Cs – Do (mg/L)
C_s	=	Concentration of saturated DO (mg/L)
L_t	=	Remaining BOD at time t = t (mg/L)
K_a	=	Reaeration coefficient (d^{-1})
K_b	=	Coefficient of organic substances decomposition (d^{-1})

When replaced the value of *Lt* into new equation, Equation would be obtained as follows:

$$D_x = \left(\frac{K_b L_o}{K_a - K_b} \right) \left(e^{-Kbt} - e^{-Kat} \right) + D_c \left(e^{-Kat} \right) \qquad \text{……………}\mathbf{(10)}$$

where:			
	D_x	=	Decreased DO at time t at the lower reaches (mg/L)
	L_o	=	Remaining BOD at time t = t (mg/L)
	D_c	=	Concentration of DO deficit that was equivalent to Cs – Do (mg/L)
	K_a	=	Reaeration coefficient (d^{-1})
	K_b	=	Coefficient of organic substances decomposition (d^{-1})
	t	=	Time (day)
	e	=	2.7183

The calculation of Ultimate carbonaceous BOD (BOD_u) at the temperature of 20°c of the river could be from the following equation (Hammer, 1986).

$$BOD_u = \frac{BOD_5}{\left(1 - 10^{-Kbt}\right)} \qquad \text{……………}\mathbf{(11)}$$

where:			
	BOD_u	=	Remaining BOD at time t = t (mg/L)
	BOD_5	=	Remaining BOD at time t = 5 (mg/L)
	K_b	=	Coefficient of organic substances decomposition (d^{-1})
	t	=	Time (day)

4.7 Oxygen Balance in the River

After assessing water quality from the study index and coefficients as well as all variables, the equation presenting the relationship was used to evaluate Reaeration rate (Rr) from oxygen transfer into the water as illustrated in Equation (12) and Deoxygenation rate (Dr) as presented in Equation (13), respectively (Ratanachai, 1996) as follows:

1) Reaeration rate: Rr

$$Rr = K_a \left(C_s - D_o \right) \qquad \text{……………}\mathbf{(12)}$$

where:			
	Rr	=	Reaeration rate (mg/L/d)
	K_a	=	Reaeration coefficient (d^{-1})
	D_o	=	Concentration of measured DO (mg/L)
	C_s	=	Concentration of saturated DO (mg/L)

2) Deoxygenation rate: Dr

The assessment of organic decomposition rate (Dr) could be calculated from the formula of Streeter and Phelps in which the concentration of BOD at different points of the river was the distance function, as demonstrated in the following equation (Streeter and Phelps, 1925).

$$Dr = -\frac{dL}{dt} = K_b L_u \qquad \text{……………}\mathbf{(13)}$$

where: Dr = Deoxygenation rate (mg/L/d)
L_u = Remaining BOD at time t (mg/L)
K_b = Coefficient of organic substances decomposition (d^{-1})
t = Time (day)

4.8 Assessment of Total Maximum Daily Load (TMDL)

Total Maximum Daily Load (TMDL) in the form of pollutant that had BOD of the river could be evaluated from the equation of Novotny (Novotny, 1989).

$$(TMDL)_u = Rr \times Q \qquad \text{.................(14)}$$

where: Rr = Reaeration rate (mg/L/d)
Q = Water flow of river (m^3/s)

$$(TMDL)_5 = (TMDL)_U \left(1 - 10^{(-Kbt)}\right) \qquad \text{.................(15)}$$

where: $(TMDL)_5$ = BOD Load at time t at the lower reach (kg/d)
$(TMDL)_u$ = BOD Load at time t at a drainage point (kg/d)

4.9 Environmental Flow Assessment

Environmental Flow Assessment by applying the mathematical models of Total Maximum Daily Load (TMDL). The process can be divided into two steps as below:

Step 1: Assessment of the value TMDL which change value DO and value BOD inspires standardized the surface water standard that is categorized by utilization. The value TMDL in this condition will apply in value assessment EF.

Step 2: Assessment of the value EF by the experiment fines water quantity that uses in mathematics model of TMDL with Trial and Error Method.

5. RESULTS

5.1 The River Reaches in the Study

Overall, the topography of Prachinburi-Bangpakong River was almost identical as all areas had the same ecological characteristics. In addition, Prachinburi River and Bangpakong River connected to each other with the length of 241 km Prachinburi-Bangpakong River in Thailand. Therefore, TMDL in Prachinburi-Bangpakong River was studied by applying the mathematical models into environmental system analysis. However, the applied mathematical models were not suitable to the area that had salt water intrusion, only the areas without salt water intrusion were selected with the length equivalent to 146 km. In order for the study of water flows in the river to be consistent to the selection of the river reaches, which based on Water Quality Monitoring Station of the Pollution Control Department. It is divided the river reaches into 5 ranges by identifying Km 0 beginning at PA5 Station as presented in Figure1.

5.2 Water Flows

The water flows from Water Quantity and Level Measurement Station of the Royal Irrigation System had annual mean from 1996-2004 between 1.4-102.5 m^3/s. The water flow from agricultural area was studied constructing the equation demonstrating the relationship between the water flow

Reach	Distance	Code	Station
		PA5	**Kabinburi Water Works** (Kabinburi District in Prachinburi)
Reach 1	38 km		
		PA4	**Ta Prachum Bridge** (Srimahaprot District in Prachinburi)
Reach 2	28 km		
		PA3	**Narongraddamri Bridge** (Meang District in Prachinburi)
Reach 3	23 km		
		PA2	**Bansrang Bridge** (Bansrang District in Prachinburi)
	30 km		
		PA1	**Estuary of Prachinburi River** (Bansrang District in Prachinburi)
Reach 4	1 km		
		BK16	**Upstream of Bangpakong River** (Bansrang District in Prachinburi)
	5 km		
		BK15	**Bangkanark Bridge** (Bangnampeaw District in Chacheangsao)
Reach 5	21 km		
		BK13	**Hua-si Temple** (Bangkla District in Chacheangsao)
The Total Distance = 146 km			

Figure 1: Division of River Ranges of Prachinburi-Bangpakong River for the Mathematical Models

and water drainage area in each station with the total of 15 stations, consisting of KGT1, KGT3, KGT9, KGT10, KGT12, KGT14, KGT18, KGT19, KGT27, KGT29, KGT15A, NY3, NY4, NY6, and NY1B. The results show that the Qr of the Reach 1, 2, 3, 4 and 5 had the mean equivalent to 11.7 m^3/s, 9.4 m^3/s, 8.1 m^3/s, 11.2 m^3/s, and 7.6 m^3/s, respectively. The precipitation of the Thai Meteorological Department had annual mean from 1996-2006 in Chachoengsao and Prachinburi Provinces were equivalent to 1,017 mm/year and 1,336 mm/year, respectively.

5.3 Pollutants in the form of Organic Substances which could be measured by BOD

The assessment of polluted water in the form of organic substances of BOD from water usage of the community, industry, farming, livestock and aquatic animal farming was done from April to March. The secondary information from each district that was gathered needed to be done. Then, the quantity of pollutants was adapted and compared to mathematical models. The quantity of pollutants was divided into 5 ranges. It was found that the amount of pollutants in the form of BOD of Reach 1, 2, 3, 4 and 5 was 10,555.9 kg/d, 7,709.1 kg/d, 5,715.7 kg/d, 6,677.7 kg/d and 9,090.1 kg/d, respectively. However, the amount of pollutants could not identify the carrying capacity of Prachinburi-Bangpakong River. The assessment of KA of each area should be done as well.

5.4 Reaeration Coefficient (Ka)

From the study of hydraulics of Prachinburi-Bangpakong River, it was found that the average flowing rate was 0.021-0.093 m/s and the average depth was 3-7 m. Therefore, the appropriate formula to calculate was Ka. The appropriate equation was O'Connor and Dobbins (1956). It was found that Ka at 20°c of reach 1, 2, 3, 4 and 5 was 0.023 d^{-1}, 0.089 d^{-1}, 0.073 d^{-1}, 0.034 d^{-1} and 0.031 d^{-1}, respectively. However, different areas and temperatures of those ranges were an important variation which could affect Ka. Thus, Ka was adjusted at any temperature. After adjusting Ka as stated above, it was found that the information and equation of Reach 1, 2, 3, 4 and 5 had month Ka as 0.230 d^{-1} , 0.089 d^{-1} , 0.073 d^{-1} , 0.034 d^{-1} and 0.031 d^{-1}, respectively. April and May, Reach 1 was highest in the amount of Ka which was 0.378 d^{-1} and 0.370 d^{-1}, respectively.

5.5 Water Quality in River

1) DO

The water quality from the Department of Pollution Control during 1996-2006 found that the concentration of Oxygen was averagely between 4.4 - 6.4 mg/L which was close to DO from

Streeter-Phelps model at Reach 1, 2, 3 and 4. The water quality was fair and it was in the standard of surface water, Class 3. The amount of DO in water was not lower than 4 mg/L. For Reach 5, water quality was low and it was in the standard of surface water, type 4. The amount of DO in water was not lower than 2 mg/L. In general, the concentration of DO would reduce according to the distance, from Reach 1, 2, 3, 4 and 5, the average was 6.4 mg/L, 6.0 mg/L, 5.5 mg/L, 5.2 mg/L and 4.4 mg/L, respectively as shown in Figure 2.

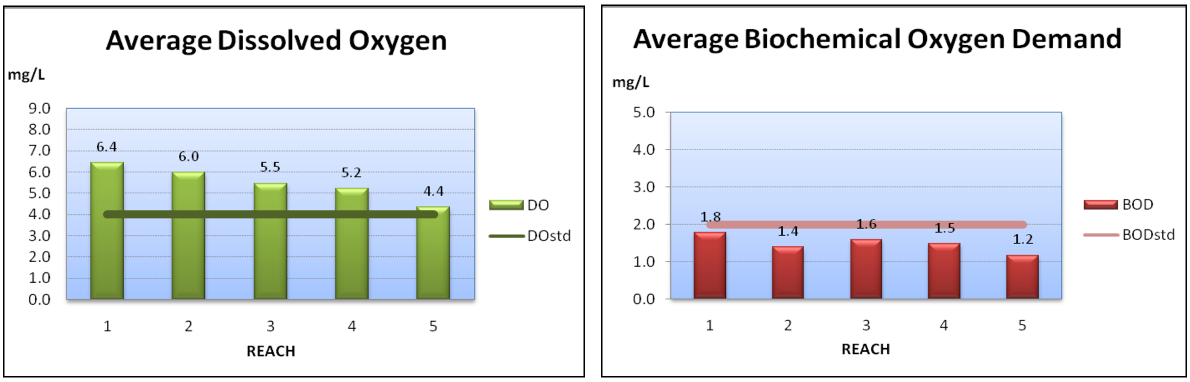

Figure 2: Averages of DO and BOD in Reach 1-5

2) BOD

The BOD was averagely between 1.2 -1.8 mg/L and was in the standard of surface water, Class 3. The BOD was set that it should not be over 2.0 mg/L. However, when considering each range, it was found that the BOD of Reach 1, 2, 3, 4 and 5 was 1.8 mg/L, 1.4 mg/L, 1.6 mg/L, 1.5 mg/L and 1.2 mg/L, respectively as shown in Figure 2. When comparing each range, it was found that the BOD was highest in Reach 1 and was lowest in Reach 5 because it was the community area which people did a lot of farming and the pollutants found were mostly organic and inorganic substances. Therefore, BOD was in relation with the amount of pollutants released to each range.

5.6 Oxygen Balance in the River

1) Deoxygenation rate (Dr)

Dr was the reaction of oxygen reduction in the water from the study of the above obtained data and equations in order to calculate Dr of Prachinburi-Bangpakong River in each range of the river. Result showed that the highest Dr was in April of the Reach 1 equivalent to 0.435 mg/L/d while the month with the lowest Dr was in April of Reach 2 equivalents to 0.070 mg/L/d, as shown in Table 1. From the study results, it was found that Dr below BOD meant the tendency of the ability in decomposing organic substances lower than existing dirtiness that was currently contaminated in the water.

2) Reaeration rate (Rr)

Rr was the reaeration into the water sources. Research results found that oxygen transfer from the atmosphere had direct relationship with water temperature, with the mean of each river range between 29.5-30.0°c. Study results of Cs, DO and Dc in each range of different months show that the month with the highest Rr was in April of the Reach 1 was 0.503 mg/L/d and The month with the lowest Rr was in February of the Reach 4 was 0.029 mg/L/d, as shown in Table 1.

3) Oxygen Balance (Rr-Dr)

The oxygen balance in the river was the model that was constructed in order to demonstrate the relation of oxygen balance as shown in Table 1, which was the sum of Dr and Rr. Therefore, the

Table 1: Rr, Dr and Oxygen Balance or the sum of Dr and Rr of Prachinburi-Bangpakong river

	Rr of Reaches (mg/L/d)					Dr of Reaches (mg/L/d)					Rr-Dr of Reaches (mg/L/d)				
MONTH	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
APR	0.503	0.365	0.279	0.100	0.132	0.435	0.275	0.315	0.309	0.266	0.068	0.090	**-0.035**	**-0.209**	**-0.134**
MAY	0.351	0.222	0.247	0.062	0.121	0.183	0.122	0.135	0.148	0.142	0.168	0.100	0.113	**-0.086**	**-0.022**
JUN	0.302	0.210	0.311	0.103	0.113	0.260	0.174	0.190	0.212	0.205	0.042	0.036	0.121	**-0.109**	**-0.092**
JUL	0.164	0.152	0.194	0.078	0.114	0.180	0.116	0.117	0.141	0.129	**-0.016**	0.036	0.077	**-0.063**	**-0.015**
AUG	0.292	0.220	0.241	0.094	0.131	0.121	0.079	0.083	0.098	0.093	0.172	0.140	0.158	**-0.004**	0.037
SEP	0.188	0.204	0.183	0.070	0.110	0.084	0.058	0.064	0.072	0.073	0.103	0.147	0.119	**-0.001**	0.038
OCT	0.152	0.189	0.220	0.090	0.169	0.109	0.076	0.087	0.094	0.098	0.043	0.113	0.133	**-0.004**	0.070
NOV	0.218	0.188	0.249	0.099	0.146	0.104	0.070	0.078	0.085	0.083	0.113	0.118	0.171	0.014	0.063
DEC	0.157	0.162	0.173	0.100	0.110	0.290	0.183	0.196	0.211	0.184	**-0.133**	**-0.020**	-0.023	**-0.111**	**-0.074**
JAN	0.226	0.265	0.317	0.086	0.095	0.240	0.144	0.151	0.159	0.129	**-0.013**	0.121	0.167	**-0.073**	**-0.033**
FEB	0.164	0.213	0.365	0.029	0.049	0.331	0.195	0.212	0.208	0.164	**-0.167**	0.018	0.153	**-0.179**	**-0.114**
MAR	0.346	0.123	0.414	0.110	0.100	0.314	0.179	0.202	0.182	0.137	0.033	-0.056	0.212	**-0.072**	**-0.037**
AVG.	0.249	0.208	0.264	0.085	0.116	0.243	0.161	0.176	0.198	0.191	0.006	0.047	0.089	**-0.113**	**-0.075**

study of Dr and Rr could be applied into the study of oxygen balance whereby in maintaining balance of the river, it required rate of change of oxygen in the water that was balanced, i.e. the sum obtained should not be negative meaning that Dr must not be higher than Rr.

5.7 Total Maximum Daily Load (TMDL)

The TMDL was the maximum quantity that the water source could have. From water quality and quantity study (Qr) of different ranges of Prachinburi-Bangpakong River. Study results showed that the quantity of water (Qr) in real condition of the Reach 1, 2, 3, 4 and 5 had the mean equivalent to 11.7 m^3/s, 9.4 m^3/s, 8.1 m^3/s, 11.2 m^3/s, and 7.6 m^3/s, respectively whereby it affected the TMDL in real condition of the Reach 1, 2, 3, 4 and 5 were equivalent to 109.9 kg/d, 73.9 kg/d, 81.3 kg/d, 36.0 kg/d, and 33.5 kg/d, respectively, as shown in Table 2 and Figure 3.

5.8 Environmental Flow (EF)

The study of the EF were obtained by Trial and Error method which changed the quantity of water flow and forecast until results became the new value of TMDL in the specified condition of the water quality to be consistent to the surface water standard, Class 3. Study results showed that the EF of the Reach 1, 2, 3, 4 and 5 had the mean equivalent to 53.9 m^3/s, 19.6 m^3/s, 11.0 m^3/s, 21.6 m^3/s, and 10.0 m^3/s, respectively whereby the highest value was in September of the Reach 1 equivalent to 213.5 m^3/s and the lowest value was in March of the Reach 5 equivalent to 0.4 m^3/s. It affected the TMDL in class3 condition of the Reach 1, 2, 3, 4 and 5 were equivalent to 506.5 kg/d, 154.6 kg/d, 110.2 kg/d, 69 kg/d and 43.9 kg/d, respectively, as shown in Table 3 and Figure 4. Moreover, this experiment results found optimize equation for Environmental Flow Assessment in Prachinburi-Bangpakong River as below:

$$EF = \left(\frac{(TMDL)_{class3}}{(TMDL)_{real}} \right) \times Q_r \qquad \text{……………….(16)}$$

where:

where:	EF	=	Environmental Flow (m^3/d)
	Q_r	=	Water Flow in the River (m^3/d)
	$(TMDL)_{Class3}$	=	TMDL in the specified condition to make the water quality congruent to the surface water standard, Class 3 (kg/d)
	$(TMDL)_{Real}$	=	TMDL in real condition (kg/d)

Table 2: $TMDL_{real}$ or Current Load that can throw and Water Flow in River (Qr) of Reach 1-5

MONTH	TMDL real (kg/d)					Qr (m^3/s)				
	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
APR	29.539	16.454	10.619	5.594	4.640	1.552	1.192	1.005	1.481	0.929
MAY	100.657	50.436	48.505	16.990	22.110	7.581	6.017	5.184	7.277	4.839
JUN	124.092	68.821	88.271	40.597	30.003	10.862	8.684	7.518	10.440	7.033
JUL	97.698	75.965	86.499	45.215	48.329	15.794	13.231	11.804	15.307	11.197
AUG	263.754	162.421	157.002	81.443	80.170	23.851	19.563	17.218	23.028	16.231
SEP	245.877	210.834	161.973	88.412	91.049	34.617	27.280	23.400	33.188	21.797
OCT	154.171	147.665	145.636	87.110	103.476	26.735	20.680	17.527	25.547	16.236
NOV	66.044	44.985	51.155	28.787	27.815	8.017	6.322	5.425	7.687	5.054
DEC	15.219	12.736	11.842	9.305	7.064	2.556	2.073	1.811	2.463	1.702
JAN	11.501	11.148	11.815	4.209	3.357	1.344	1.112	0.985	1.300	0.931
FEB	5.226	5.432	8.087	0.884	1.025	0.841	0.675	0.586	0.809	0.548
MAR	5.892	1.582	4.438	1.780	0.985	0.450	0.340	0.283	0.428	0.261
AVG.	109.946	73.860	81.278	35.965	33.454	11.694	9.375	8.130	11.246	7.612

Table 3: $TMDL_{class3}$ or Load that can throw and EF or Minimum Demand of Water Reservation of Reach 1-5

MONTH	TMDL Class 3 (kg/d)					EF (m^3/s)				
	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
APR	73.960	20.833	14.144	8.933	5.427	3.886	1.509	1.339	2.365	1.087
MAY	365.545	91.776	65.625	43.418	26.765	27.532	10.948	7.014	18.598	5.858
JUN	459.139	143.899	102.647	66.788	40.593	40.190	18.157	8.742	17.176	9.515
JUL	611.899	197.953	142.305	91.197	62.286	98.923	34.477	19.419	30.873	14.431
AUG	1082.302	327.595	236.497	133.986	90.287	97.871	39.457	25.936	37.886	18.279
SEP	1516.244	465.289	315.421	201.039	124.771	213.472	60.204	45.568	75.465	29.870
OCT	1140.864	341.474	229.040	161.153	93.381	197.841	47.822	27.564	47.262	14.652
NOV	349.087	110.964	71.060	48.414	26.339	42.377	15.594	7.536	12.928	4.786
DEC	108.221	33.962	26.135	15.270	10.320	18.178	5.528	3.998	4.042	2.486
JAN	59.681	19.110	14.345	8.332	5.623	6.976	1.907	1.196	2.573	1.559
FEB	32.730	10.579	7.672	4.709	3.162	5.270	1.314	0.556	4.312	1.691
MAR	19.048	5.579	4.186	2.708	1.658	1.455	1.198	0.267	0.651	0.439
AVG.	506.454	154.612	110.205	69.027	43.903	53.867	19.625	11.024	21.584	9.989

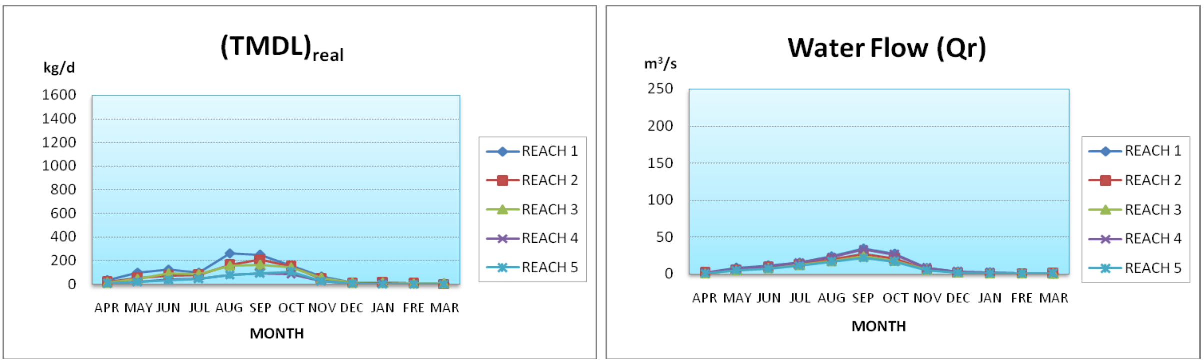

Figure 3: $TMDL_{real}$ or Current Load that can throw and Water Flow in River (Qr) of Reach 1-5

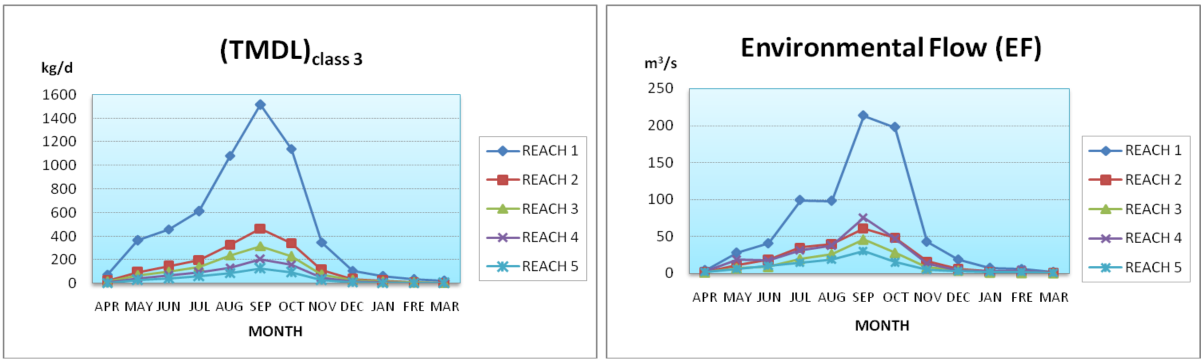

Figure 4: $TMDL_{class3}$ or Load that can throw and Environmental Flow (EF) or Minimum Demand of Water Reservation of Reach 1-5

6. CONCLUSIONS

The assessment of the environmental water demand and Total Maximum Daily Load (TMDL) of Prachinburi-Bangpakong River by applying the mathematical models in order to study water quality, assess the TMDL in the form of pollutants that had BOD and evaluate Environmental Flows (EF) or minimum demand of water reservation, respectively. In this studying, the river was selected with the distance of 146 km as freshwater ranges and was divided into five reaches which based on Water Quality Monitoring Station of the Pollution Control Department.

1) The Water Quality of Prachinburi-Bangpakong River

It was found that the water quality from April to March was still in the standard of surface water, Class 3. Medium clean fresh surface water resources used for: agriculture and consumption, but passing through an ordinary treatment process before use. The value of DO was not lower than 4 mg/L and the value of BOD was not more than 2 mg/L. Research results indicated that in studying the water quality obtained from measurement by Water Quality Monitoring Station during 1996-2006 were the mean of DO was between 4.4-6.4 mg/L and BOD was between 1.2-1.8 mg/L and the water quality calculated by the mathematical models were the mean of DO was between 4.9-6.8 mg/L and BOD was between 1.7-2.1 mg/L. It was found that both of the results had similar trend because it was in the standard of surface water, Class 3.

2) Total Maximum Daily Load (TMDL)

The results showed that the value of TMDL in real condition ($TMDL_{real}$) of the ranges were in the relatively low level between 0.9 - 263.8 kg/d. The Reach 1, 2, 3, 4 and 5 were equivalent to 109.9 kg/d, 73.9 kg/d, 81.3 kg/d, 36.0 kg/d, and 33.5 kg/d, respectively. After that, the TMDL was assessed again as TMDL in Class 3 ($TMDL_{class3}$) for healthy river; therefore, both of DO and BOD were assumed the values as Class 3 also. Studied results showed that the value of TMDL in Class 3 condition ($TMDL_{class3}$) of the ranges were between 1.7 - 1516.2 kg/d. The Reach 1, 2, 3, 4 and 5 were equivalent to 506.5 kg/d, 154.6 kg/d, 110.2 kg/d, 69.0 kg/d, and 43.9 kg/d, respectively. After that, this TMDL will be applied for assessment the value of EF.

3) Environmental Flow (EF)

The minimum water demand of reservation for healing equilibrium natural of Prachinburi-Bangpakong River was assess as the value EF by the experiment fines water quantity that uses in mathematics model of TMDL with Trial and Error Method. Studied results showed that the value of

EF in Class 3 condition of the Reach 1, 2, 3, 4 and 5 were equivalent to 53.9 m^3/s, 19.6 m^3/s, 11.0 m^3/s, 21.6 m^3/s and 10.0 m^3/s, respectively. The mean of EF in Class 3 condition was between 10 - 53.9 m^3/s. This identified condition will enable better water quality and carrying capacity of the river. Therefore, the water flow in Class 3 condition was limited to be EF which was minimum demand of water reservation with good water quality for utilizations throughout the year of Prachinburi-Bangpakong River. However, studied results still must have good administrations of water resource from institutes or experts in pertaining to water resource both of the water quality and quantity. They would share build the trend in the administration that is appropriate or make the defensive measure and decrease environment effect for the future.

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