ORIGINAL ARTICLE

Water level change by tidal regulator in the Bang Nara River

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Abstract

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The interaction between tide and salinity barrier can be investigated using both analytical model and numerical model when the structure is located at some distance (62 km) from the river mouth of the Bang Pakong River as shown by Vongvisessomjai and Srivihok (2003). However, when the structure is located near the river mouth of the Bang Nara River, the numerical model yields negligible reflection of tide and underestimates observed water levels while the analytical model provides a good prediction. It is found from this study that semi-diurnal tides M_2 and S_2 are strongly affected by construction of tidal regulator having amplification factor of more than 100 percent while diurnal tides are less sensitive to the construction having amplification factor of about 30 percent for K_1 and about zero percent for O_1.

Key words : analytical model, salinity barrier, tidal regulator, tide reflection

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บทคัดย่อ

สุภัทท์ วงศ์วิเศษสมใจ สุทัศน์ วีสกุล และ ภัทรชนก ศรีวิหค

การเปลี่ยนแปลงระดับน้ำโดยคันกั้นน้ำเค็มในแม่น้ำบางนรา

ว. สงขลานครินทร์ วทท. 2546 25(6) : 757-771

การกระทำระหว่างคลื่นน้ำขึ้นน้ำลงกับคันกั้นน้ำเค็ม สามารถวิเคราะห์โดยใช้แบบจำลองทางทฤษฎีและแบบจำลองทางคณิตศาสตร์ เมื่อคันกั้นน้ำเค็มอยู่ไกล (62 กิโลเมตร) จากปากแม่น้ำบางปะกง ซึ่งศึกษาโดย วงศ์วิเศษสมใจ และศรีวิหค (2003) แต่เมื่อคันกั้นน้ำเค็มอยู่ใกล้ปากแม่น้ำบางนรา แบบจำลองทางคณิตศาสตร์ให้ค่าสะท้อนกลับของคลื่นน้ำขึ้นน้ำลงต่ำมาก เมื่อเปรียบเทียบกับค่าที่วัดได้จริง ในขณะที่แบบจำลองทางทฤษฎีให้ค่าที่ถูกต้อง จากการศึกษานี้พบว่าคลื่นน้ำขึ้นน้ำลงชนิดน้ำคู่ M_2 และ S_2 มีปฏิกิริยาอย่างมากกับคันกั้นน้ำเค็ม โดยมีสัมประสิทธิ์การเพิ่มมากกว่า 100% ในขณะที่คลื่นน้ำขึ้นน้ำลงชนิดน้ำเดี่ยวมีปฏิกิริยาน้อยกว่า โดยมีสัมประสิทธิ์การเพิ่มประมาณ 30% สำหรับ K_1 และประมาณ 0% (ไม่มีปฏิกิริยา) สำหรับ O_1

สาขาวิศวกรรมแหล่งน้ำและการจัดการ สำนักวิชาวิศวกรรมโยธา สถาบันเทคโนโลยีแห่งเอเชีย ตู้ ปณ.4 อำเภอคลองหลวง จังหวัดปทุมธานี 12120

Tidal barrier is a kind of estuary structure which has a role to protect the salinity intrusion and store freshwater during low river discharge and also protect flooding during flood tide and high storm surge from the sea. There are various utilizations of the tidal barrier such as Thames Barrier in England and the Delta Plan Project in the Netherlands, which are located at the river mouth and the estuary barrage of the Nagara River in Japan, which is located 5.4 km from the river mouth. However, if a tidal barrier constructed at some distance in the tidal reach, water level change from the tide reflection will create an adverse effect in the downstream area. The salinity barrier in the Bang Pakong River, Thailand located about 62 km from the river mouth caused a tidal range magnification in the downstream side. River bank collapse and overspill of salinewater were the consequences of the operation.

The Bang Nara River is situated in the northeastern part of Narathiwat Province and the total drainage area of the Bang Nara River, 1,401 km^2, is penetrated with a total length of about 60 km through the low-lying coastal plain along the east coast of the Thai peninsula. The Bang Nara River is tidal and brackish throughout the entire reach being directly affected by the tidal oscillations with salinity intrusion into the river during the high tides. Therefore, this condition caused an ineffective utilization of the freshwater for agriculture (JICA, 1986).

In 1990, the Upper Tidal Regulator located 6 km upstream of the Bang Nara river mouth and about 1 km downstream of Yakang River confluence as shown in Figure 1, was constructed to prevent salinity intrusion and to provide freshwater supplied to the irrigation development, as well as reduce the annual inundation over the low-lying area along the Bang Nara River. However, the tidal regulator operation effect an increase in the water level fluctuation in the downstream course. In this study, the water level changed by the tidal regulator in the Bang Nara River was investigated for insight into the impact of barrier structure to the water level in the estuarine area.

Theoretical Considerations

The behavior of water level in the tidal reach affected by tidal regulator is analyzed by consideration of each tide constituent reflecting at the closed end.

1. Harmonic Analysis of Tide

Normally, the observed water level in the tidal reach shows complicated patterns. Harmonic

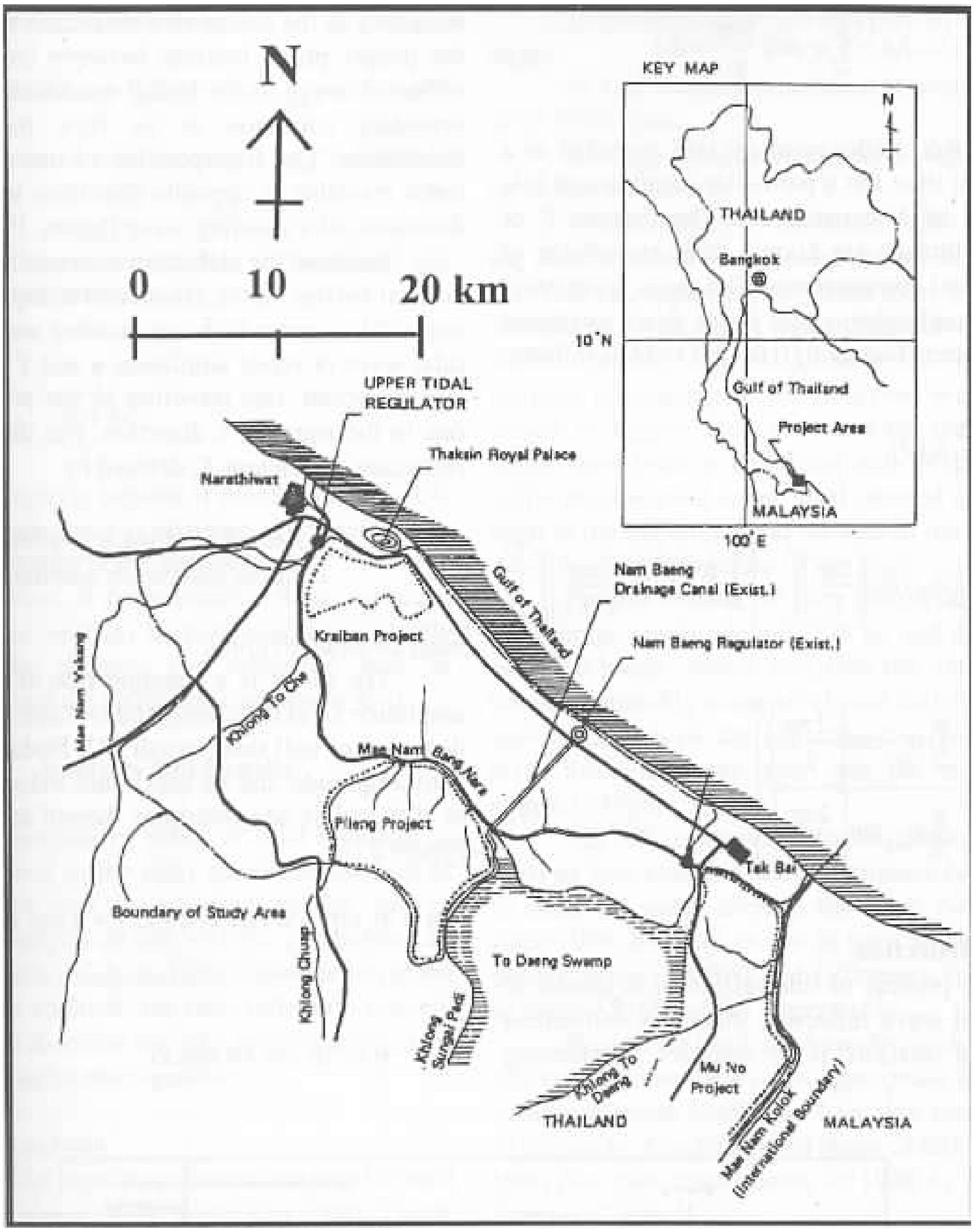


Figure 1. Location map of tidal regulator in the Bang Nara River. (Source: JICA, 1986)

analysis can be properly applied for separating tide which is composed of various constituents and characterizing it as a function of time and location.

The harmonic analysis of tides is developed from the following two premises:

1. The resultant tide at any location is composed of a finite number of constituents, each with its own periodicity, phase angle and amplitude.

2. The constituents are each simple harmonics in time and are mutually independent.

$$\eta_r(t) = \Delta h + \sum_{i=1}^{N} a_i sin[\frac{2\pi t}{T_i} + \delta_i] \quad (1)$$

in which $\eta_r(t)$ is the resultant tide recorded as a function of time t at a particular location and it is composed of N constituents. The periods T_i of the i-constituents are known from knowledge of astronomical computations. The mean water level Δh, the amplitudes a_i and phase δ_i are evaluated from a discrete hourly $\eta_r(j)$ for j=1 to M as follows:

$$\Delta h = \frac{1}{M}\sum_{j=1}^{M} \eta_r(j) \quad (2)$$

$$a_j = 2\left[\left\{\frac{1}{M}\sum_{j=1}^{M}\eta_r(j)\sin\left[\frac{2\pi j}{T_i}\right]\right\}^2 + \left\{\frac{1}{M}\sum_{j=1}^{M}\eta_r(j)\cos\left[\frac{2\pi j}{T_i}\right]\right\}^2\right]^{1/2} \quad (3)$$

$$\delta_i = \tan^{-1}\left[\frac{\sum_{j=1}^{M}\eta_{r(j)}\cos\left[\frac{2\pi j}{T_i}\right]}{\sum_{j=1}^{M}\eta_{r(j)}\sin\left[\frac{2\pi j}{T_i}\right]}\right] \quad (4)$$

2. Tide Reflection

The process of tide reflection is similar to the normal wave reflection theory. A convenient method of analysis is to consider a reflecting boundary as the source of a secondary wave train, the proper phase relation between incident and reflected wave train being established by the boundary condition of no flow through the boundaries. The superposition of two such wave trains traveling in opposite directions leads to the formation of a standing wave (Ippen, 1966).

Suppose the reflection is caused by a plane vertical barrier. In the absence of dissipation, thus two tidal waves which are incident and reflected tidal wave of equal amplitude a and T period are superimposed, one traveling in the positive and one in the negative x direction. For this case the reflection coefficient K_r defined by

$$K_r = \frac{Reflected\ tidal\ wave\ amplitude}{Incident\ tidal\ wave\ amplitude} \quad (5)$$

must be equal to unity.

The result is a standing tide of maximum amplitude 2a at the closed end x=0 and at multiple distances of half tidal length L/2. Nodal points of zero amplitude and of maximum velocities exist at L/4 and at odd multiples thereof as shown in Figure 2.

$$\eta = \eta_1 + \eta_2 = a\ cos\ (\sigma t - kx) + a\ cos\ (\sigma t + kx) \quad (6)$$

or

$$\eta = 2a\ cos\ \sigma t\ cos\ kx \quad (7)$$

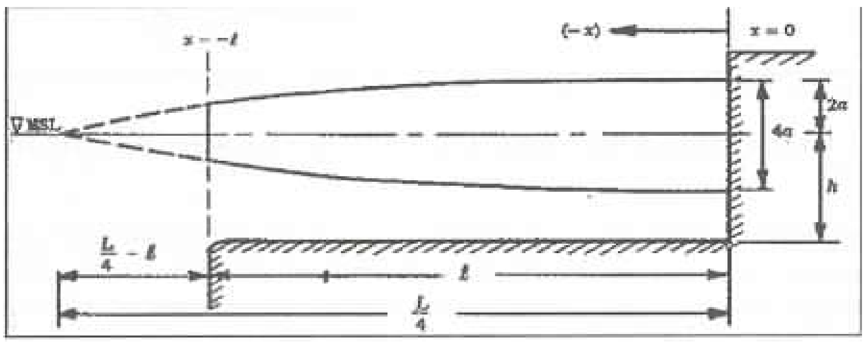


Figure 2. Tide entering channel of finite length with reflection end.

Thus high water is obtained by

at the closed end: $x = 0$ for $t = 0$, $\eta_{0\,\max} = 2a$ (8)

at the open end: $x = -\ell$ for t=0, $\eta_{(-\ell)\max} = 2a\cos k\ell$ (9)

The ratio of the maximum tide at the closed end to the tide at the entrance is

$$\frac{\eta_{o\max}}{\eta_{(-\ell)\max}} = \frac{1}{\cos k\ell} \qquad (10)$$

Hence this ratio is infinite if $kl=\pi/2$ for ℓ/L=1/4. Note that high water is obtained at the same time ($t=0$) everywhere in the channel.

However, if the reflection does not occur from a plane vertical barrier which completely obstructs the channel, the reflection may be incomplete and the reflection coefficient K_r<1.

Analysis and Results

The analysis of effect of tidal regulator to the water level in the tidal reach downstream of the regulator was investigated by the use of harmonic analysis of tide and the comparison of tidal amplitude before and after construction of the regulator. In addition, the tidal reflection concept was used to describe the tide amplification characteristics nearby the regulator.

1. Yearly Analysis

The tidal regulator construction was finished and started operation in September 1990. Therefore, the available data since year 1987 to 1989 were used for representing the condition before operation and data in year 1991 to 2001 were used for the condition after operation. Normally, short term harmonic analysis of water level in the Gulf of Thailand is based on the four main tide constituents (Vongvisessomjai and Rojanakamthorn,2000) which are:

1) Principal lunar M_2 with a period of 12.4206 hours.

2) Principal solar S_2 with a period of 12.0000 hours.

3) Luni-solar declinational K_1 with a period of 23.9346 hours.

4) Large lunar declinational O_1 with a period of 25.8194 hours.

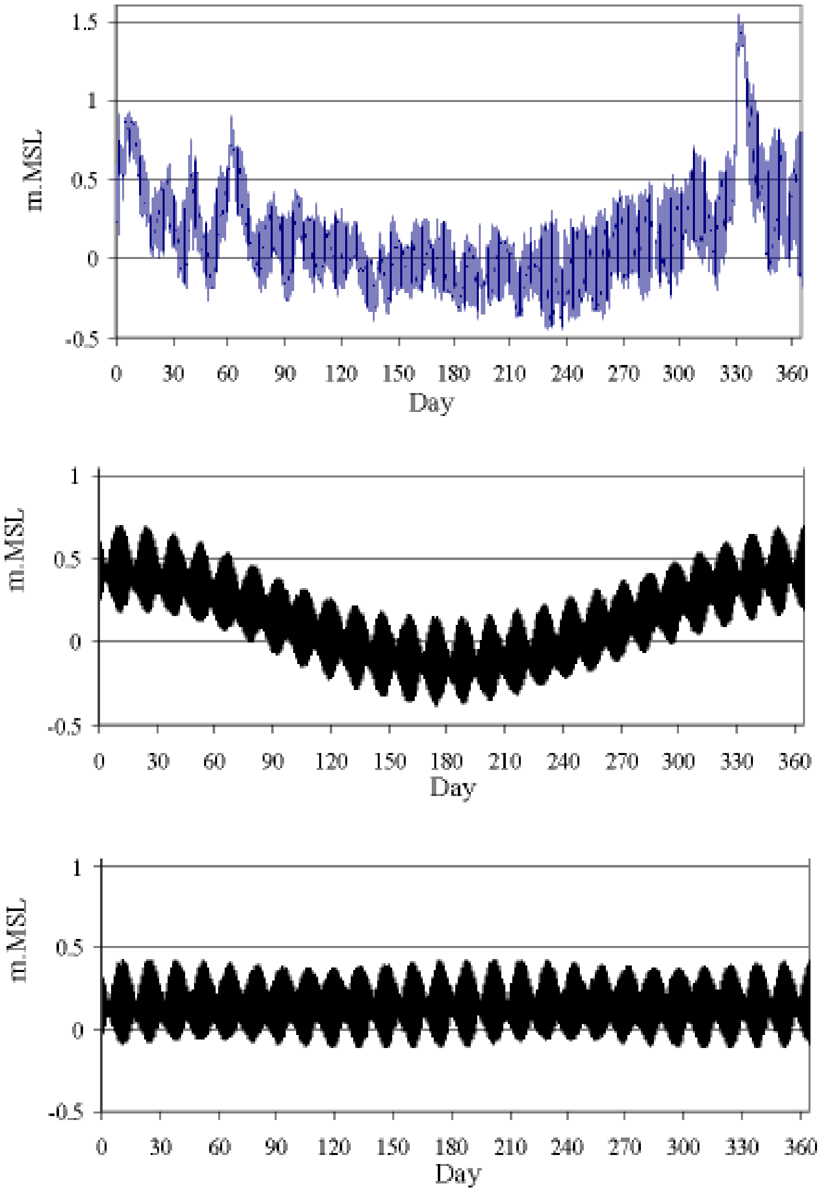
The envelopes of observed water levels at the tidal regulator in 1986 are shown in Figure 3 (a). The calculated water levels from four main constituents with mean water level Δh=0.137 m, which typically are not suitable for long term analysis comparing to the observed water level shown in Figure 3(c), provided the constant of mean water level or unvarying axis of fluctuation while the observed water level showed a the high level at the beginning and the end of the year and a low level at the middle of the year.

For this reason, the long period tide S_a with the average amplitude of 0.278 m. and the period of 8,780 hours, which describes the variation of the mean monthly water level, was included in the harmonic analysis for adjusting the mean water level throughout the year and the result was shown in Figure 3(b).

The efficiency evaluation of computed water level by four and five tide constituents comparing to observed water level in the Bang Nara River since 1986-2001 are shown in term of Root Mean Square Error (RMSE) and Efficiency Index (EI) in Figures 4(a) and (b) respectively.

Figures 4(a) and (b) show obviously that five tide constituents were more appropriate to use for computed water level than four tide constituents in this study. Amplitude and phase of tide obtained from five tide constituents in 1986 to 2001 are shown in Table 1.

The construction of tidal regulator induced reflection of the tidal wave during closing the gate. The amplitude of each tide constituent before constructing the regulator (1986-1989) was compared to amplitude of the tide after construction of the regulator Figures 5(a) and (b) show the variation of mean water level and tide amplitude at the tidal regulator in the downstream side. There strange results could be seen in Figure 5(b) that all the four amplitudes of tide in 1987 and 1989



(a)

(b)

(c)

Figure 3. (a) Observed water levels at tidal regulator station in 1986.
(b) Computed water levels from five tide constituents in 1986.
(c) Computed water levels from four tide constituents in 1986.

before the construction of tidal regulator were unreasonably high while all the four amplitudes of tide in 1995 after the construction of tidal regulator were unreasonably low. Construction of tidal regulator and closure dam had started in 1989 which resulted in unreasonably high value of four amplitudes of tide.

The tidal properties before constructing the tidal regulator were used to calculate the arithmetic mean from value in Table 1 in year 1986 to 1989 except the strange values of 1987 and 1989, and tidal properties after the tidal regulator construction were used to calculate the arithmetic mean from values of year 1991 to 2001 except value of

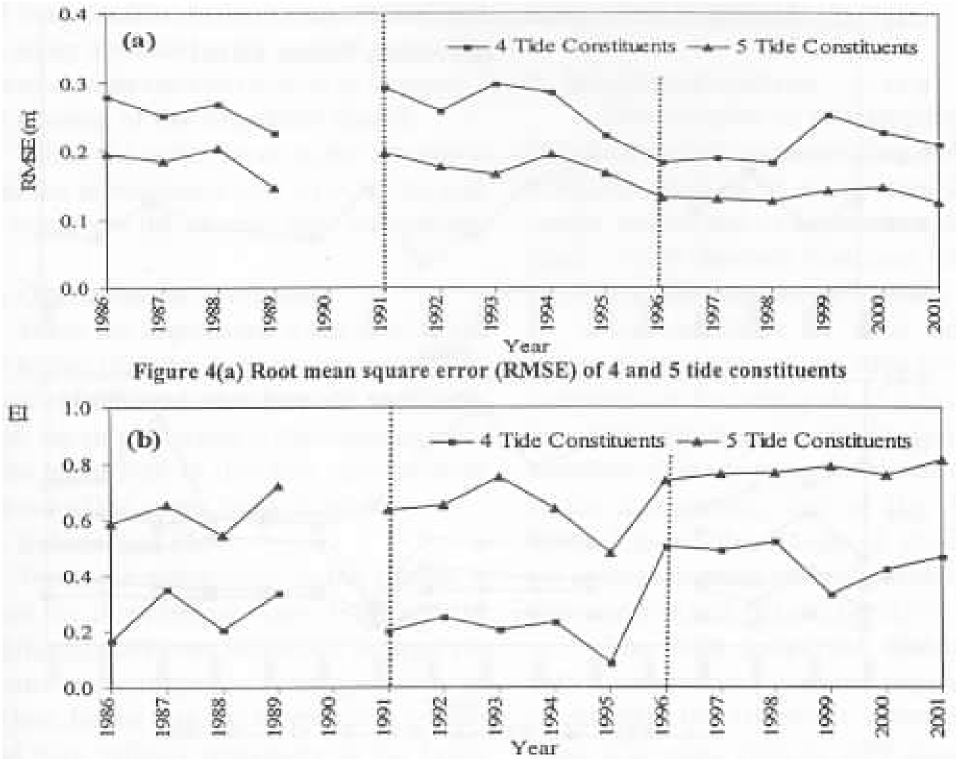


Figure 4. (a) Root mean square error (RMSE) of 4 and 5 tide constituents.
(b) Efficiency index (EI) of 4 and 5 tide constituents.

Table 1. Harmonic analysis for yearly data.

year	Δh (m)	M_2		S_2		K_1		O_1		S_a		$\frac{(K_1+O_1)}{(M_2+S_2)}$
		a_1 (m)	δ_1 (rad)	a_2 (m)	δ_2 (rad)	a_3 (m)	δ_3 (rad)	a_4 (m)	δ_4 (rad)	a_5 (m)	δ_5 (rad)	
1986	0.137	0.056	0.446	0.027	1.839	0.134	1.162	0.088	-0.228	0.279	1.536	2.649
1987	0.098	0.106	2.608	0.048	2.232	0.204	1.584	0.116	1.888	0.243	1.557	2.082
1988	0.182	0.067	4.284	0.032	2.074	0.152	1.418	0.092	3.407	0.239	1.569	2.462
1989	0.120	0.089	-0.618	0.041	2.293	0.177	1.631	0.099	-1.546	0.208	1.713	2.125
1990	-	-	-	-	-	-	-	-	-	-	-	-
1991	0.190	0.099	2.787	0.043	2.107	0.153	1.781	0.085	1.934	0.306	1.649	1.672
1992	0.160	0.103	4.694	0.049	2.073	0.161	1.780	0.082	3.800	0.266	1.657	1.604
1993	0.085	0.110	-0.104	0.052	2.333	0.154	1.902	0.081	-1.057	0.353	1.387	1.452
1994	0.039	0.118	1.686	0.052	2.399	0.161	1.910	0.079	0.788	0.300	1.725	1.412
1995	0.151	0.052	3.262	0.027	1.846	0.062	1.561	0.044	2.344	0.207	1.479	1.360
1996	0.074	0.152	-O.857	0.072	2.721	0.180	2.032	0.084	4.595	0.178	1.772	1.175
1997	0.086	0.156	0.478	0.070	2.810	0.185	2.020	0.080	-0.312	0.198	1.632	1.172
1998	0.091	0.159	2.251	0.071	2.781	0.189	1.936	0.082	1.557	0.184	1.625	1.175
1999	0.130	0.143	3.831	0.066	2.617	0.179	1.794	0.087	3.277	0.340	1.434	1.276
2000	0.074	0.148	-0.587	0.072	2.687	0.198	1.830	0.096	-1.178	0.245	1.475	1.331
2001	0.084	0.148	0.758	0.070	2.755	0.204	1.817	0.100	0.139	0.240	1.577	1.401

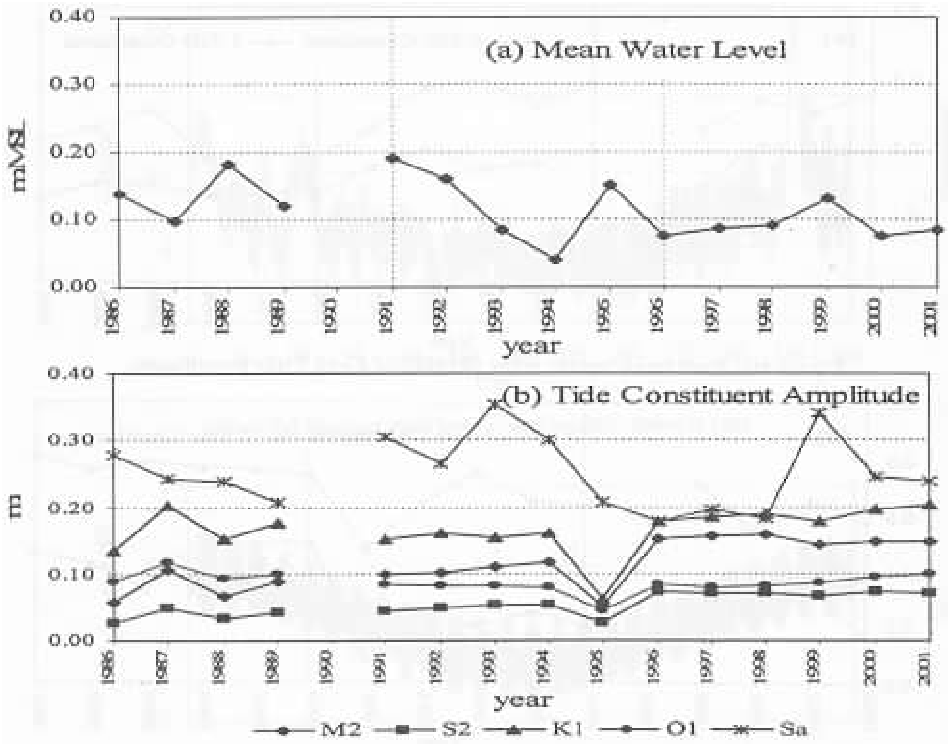


Figure 5. Changing of mean water level and tide amplitude from yearly analysis.

year 1995 (Table 2). The results showed that each component had different increase in amplitude. The semi-diurnal tide had a larger amplification than the diurnal tide, in particular the large lunar declinational O_1 showed a decreasing tidal amplitude. Considering the ratio between the amplitudes of the major diurnal and semidiurnal components: $(K_1+O_1)/(M_2+S_2)$, a mixed tide type was observed but after construction of the regulator this ratio was reduced. However, the real operation of the tidal regulator has not been the permanent fully closed operation. As to the purposes of the gate were to keep the freshwater in the Bang Nara storage as well as to prevent seawater intrusion from the Gulf of Thailand through the downstream rivers. Hence, the tidal regulator is operated so that the inflow into the Bang Nara water storage can be rapidly discharged to the Gulf of Thailand during

Table 2. Summary of tidal properties change from yearly analysis.

Tidal Properties	Mean Water Level Δh (m)	Amplitude M_2 (m)	Amplitude S_2 (m)	Amplitude K_1 (m)	Amplitude O_1 (m)	Amplitude S_a (m)	$\frac{(K_1+O_1)}{(M_2+S_2)}$
Before Construction (1986-1989)	0.160	0.062	0.030	0.143	0.090	0.259	2.56
After Construction (1991-2001)	0.101	0.134	0.062	0.177	0.086	0.261	1.36
% Increase	-36.9	116	107	23.8	-4.4	0.8	-

the flood stage, while maintaining normal impounding water level during the normal stage. The procedure to operate the tidal gate is as follows:

(a) Closing of the Regulator Gates.

When the water level in the storage is lower than the downstream tide level, every gate is closed to prevent the adverse flow and salinity intrusion.

(b) Operation for Overflow.

When the impounded water level in the storage is higher than the downstream water level and the vertical difference between the two levels is not large, the surplus water is discharge as overflow by the upper leaf. In this way, the operation of drop-down of the upper leaf is timely.

(c) Submerged Flow

When the water level in the storage is higher than the downstream water level and the vertical difference between two levels is large, the surplus water is discharged as submerged flow by the lower leaf. In this way, the lower leaf is opened partly and high salinity remaining in the lower layer of the Bang Nara storage can be discharged.

(d) Fully Opening

When a large amount of inflow into the storage during the flood is discharged through the tidal regulators, every gate is fully opened. The highest amplification of tide occurs during the fully closed tidal gate and in this study data on the operation of tidal regulator in 2001 has been considered and listed in Table 3.

The real operation in 2001 showed that the operation can be separated into two parts. January to March and October to December can be defined as flood period with the average duration of closed operation = 11% and April to September can be defined as dry period with the average duration of closed operation = 54%. Due to longer period of closed operation duration, the amplification of tide in dry period is more significant compared to all year analysis. Moreover, even though there was some opened operation in some periods the gate opening is quite small and closed in a short time, hence tide propagation to upstream is negligible. The gate opening in July 2001 is shown in Figure 6. Therefore, this specific dry period was analyzed using another approach.

2. Dry Period Analysis

The variation of tide amplitude before and after tidal regulator construction was evaluated by harmonic analysis of water level during the dry period from April to September. Amplitude and phase of tide obtained from four tide constituents in 1986 to 2001 are shown in Table 4.

The amplitude of each tide constituent before constructing of the dam (1986-1989) was compared to the amplitude of tide after construction of the regulator. Figures 7(a) and (b) show the variation of mean water level and tide amplitude at the downstream side of the tidal regulator. Table 2 shows the change of yearly analysis on the arithmetic mean of tidal properties before and after construction of tidal regulator.

The tidal properties during dry period before constructing the tidal regulator were used to calculate the arithmetic mean from values in Table 4 in years 1986 to 1989 except the strange results of 1987 and 1989, and the tidal properties after the tidal regulator construction were used to calculate the arithmetic mean from values of years 1991 to 2001 except strange results of 1995 and 1999 (Table 5).

Table 3. Tidal regulation operation.

Month (2001)	**% of Closed Operation** $= \dfrac{\textit{No. of Closed Operation Day}}{\textit{No. of Total Day}}$
January	10
February	18
March	23
April	58
May	55
June	47
July	65
August	55
September	45
October	0
November	3
December	13

Table 4. Harmonic analysis for dry period data (April-September).

Year 6 months Analysis	Δh (m)	M_2		S_2		K_1		O_1		$\frac{(K_1+O_1)}{(M_2+S_2)}$
		a_1 (m)	δ_1 (rad)	a_2 (m)	δ_2 (rad)	a_3 (m)	δ_3 (rad)	a_4 (m)	δ_4 (rad)	
1986	-0.039	0.050	-0.516	0.026	1.505	0.136	2.479	0.091	3.772	2.978
1987	-0.049	0.112	1.986	0.052	2.179	0.223	3.148	0.124	-0.303	2.107
1988	0.033	0.064	3.095	0.029	1.941	0.154	2.826	0.088	0.735	2.608
1989	-0.029	0.110	-1.230	0.051	2.332	0.217	3.208	0.117	2.681	2.072
1990	-	-	-	-	-	-	-	-	-	-
1991	-0.006	0.119	2.203	0.052	2.182	0.200	3.360	0.105	-0.296	1.778
1992	-0.014	0.111	3.650	0.055	2.203	0.181	3.300	0.090	1.182	1.630
1993	-0.144	0.117	-0.707	0.054	2.390	0.179	3.435	0.092	3.032	1.584
1994	-0.156	0.138	1.133	0.061	2.434	0.185	3.521	0.092	-1.336	1.397
1995	0.015	0.042	1.149	0.018	1.216	0.063	2.395	0.039	-1.200	1.705
1996	-0.037	0.162	4.395	0.075	2.761	0.188	3.581	0.084	1.978	1.146
1997	-0.039	0.152	-0.161	0.063	2.831	0.185	3.567	0.078	3.852	1.222
1998	-0.025	0.160	1.630	0.069	2.763	0.196	3.486	0.086	-0.644	1.235
1999	-0.098	0.094	3.289	0.044	2.567	0.117	3.253	0.055	1.182	1.252
2000	-0.082	0.153	4.215	0.073	2.755	0.203	3.406	0.093	2.090	1.314
2001	-0.065	0.152	0.113	0.067	2.784	0.217	3.355	0.107	4.290	1.474

Table 5. Summary of tidal properties change from dry period analysis.

Tidal Properties	Mean Water Level Δh (m)	Amplitude M_2 (m)	Amplitude S_2 (m)	Amplitude K_1 (m)	Amplitude O_1 (m)	$\frac{(K_1+O_1)}{(M_2+S_2)}$
Before Construction (1986-1989)	-0.003	0.057	0.028	0.145	0.090	2.76
After Construction (1991-2001)	-0.063	0.141	0.063	0.193	0.092	1.43
% Increase	2,000	147	125	33.1	2.2	-

Table 6. Amplification factor of each tide constituents.

Tide Factor (%)	M_2	S_2	K_1	O_1
Yearly Analysis	116	107	23.8	-4.4
Dry Period Analysis	147	125	33.1	2.2
Average	132	116	28.5	-1.1

The results of dry period data analysis are similar to the yearly analysis and the average amplification factor for each tide constituent is shown in Table 6.

The observed water levels recorded before and after the construction of the regulator at the same location at the downstream side of the regulator are shown in Figure 8. These amplifica-

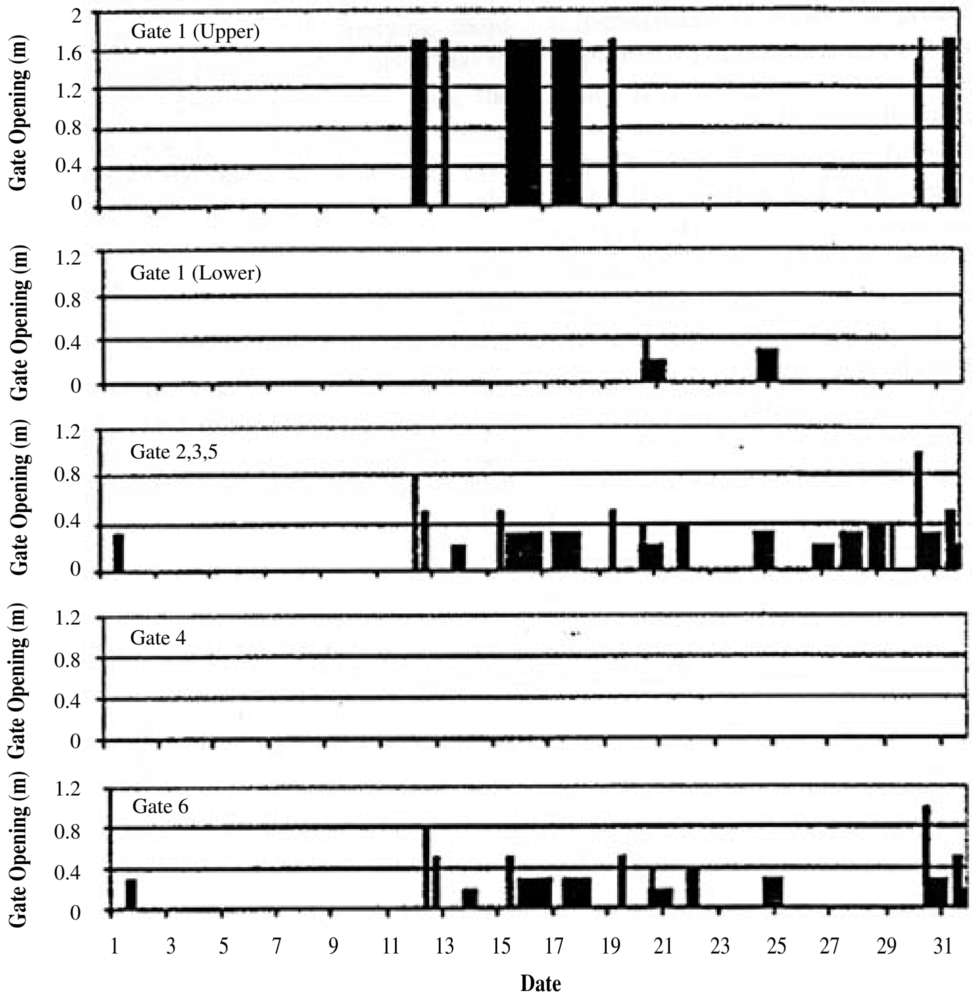


Figure 6. Gate opening in July 2001. (Sources: RID, Thailand)

Table 7. Efficiency of two computation approaches.

Month	% of Closed Period	Amplification Factor in Table 6				2-Time Amplification Factor			
		EI	RMSE (m)	ΔMax (m)	ΔMin (m)	EI	RMSE(m) (m)	ΔMax (m)	ΔMin (m)
Apr	58	0.610	0.135	0.328	0.155	0.378	0.171	0.128	0.037
May	55	0.555	0.160	0.205	0.240	0.455	0.177	0.008	0.050
Jun	47	0.259	0.218	0.342	0.451	0.263	0.218	0.141	0.265
Jul	65	0.568	0.155	0.320	0.288	0.623	0.145	0.113	0.112
Aug	55	0.568	0.145	0.344	0.312	0.504	0.156	0.130	0.143
Sep	45	0.719	0.109	0.285	0.165	0.505	0.144	0.076	0.019
Apr-Sep	-	0.516	0.157	0.344	0.451	0.486	0.170	0.141	0.265

whereas $\Delta Max = Max\,|\max_{observed\ water\ level} - \max_{computed\ water\ level}|$
and $\Delta Min = Max\,|\min_{observed\ water\ level} - \min_{computed\ water\ level}|$

tion factors were rechecked by applying them active to predict water level after the operation of tidal regulator. The data in year 1986 were the represent of the water level under the natural condition or before the operation. Each tide constituent was multiplied by the averaged amplification factor, after that, the results were compared with the water level data during real operation in year 2001. The results of predicted water levels during dry period in April to September 2001 were shown in Figure 9.

Normally, tidal pattern at the same location is similar for each year but mean water level might be different according to the river discharge which is inconsistent. However, the predicted water level in Figure 9 is computed from the averaged factor which is representative of whole period when the real operation is really complicated and varied with time. In case of permanent fully closed operation and full reflection and no energy loss, the factor of each tide constituent is supposed to be twice magnitude of the incident tide at the tidal regulator location. This condition can be used for simplifying the most severe case or maximum The comparison of water level before and after the operation of regulator is shown in Figure 10.

It can be seen that the 2-times factor provided the higher fluctuation and amplification

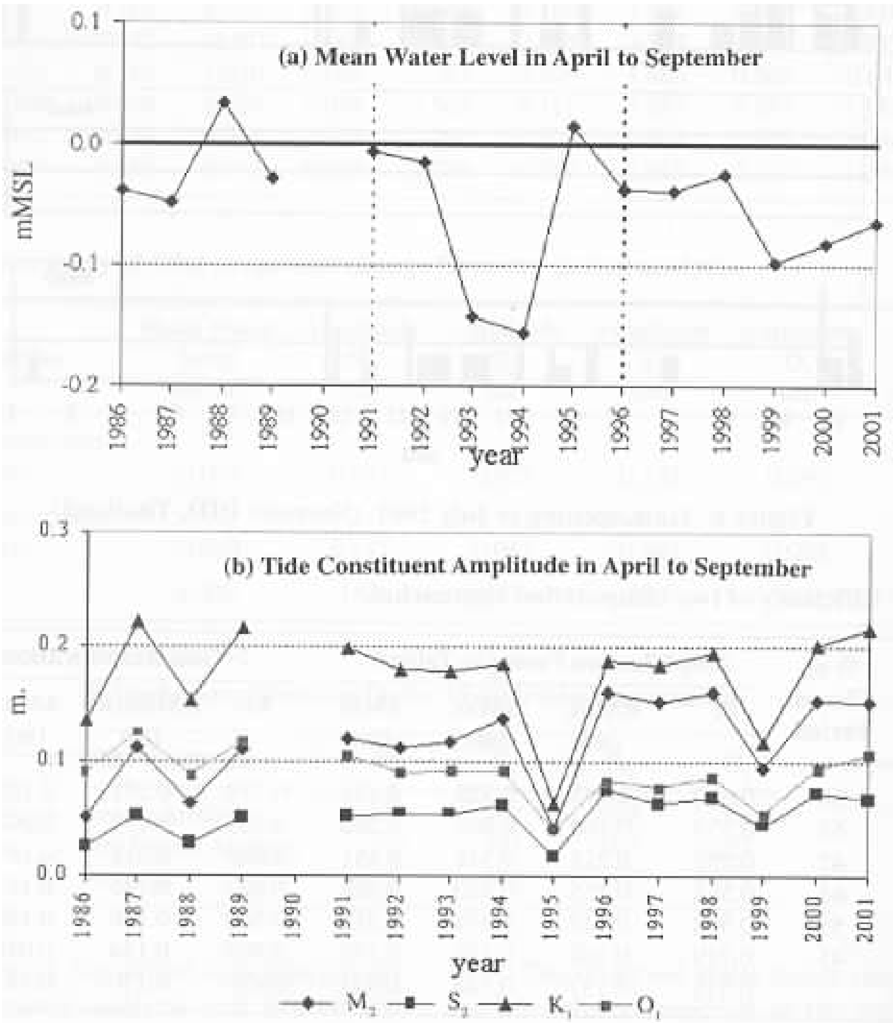


Figure 7. Changing of mean water level and tide amplitude from dry period analysis.

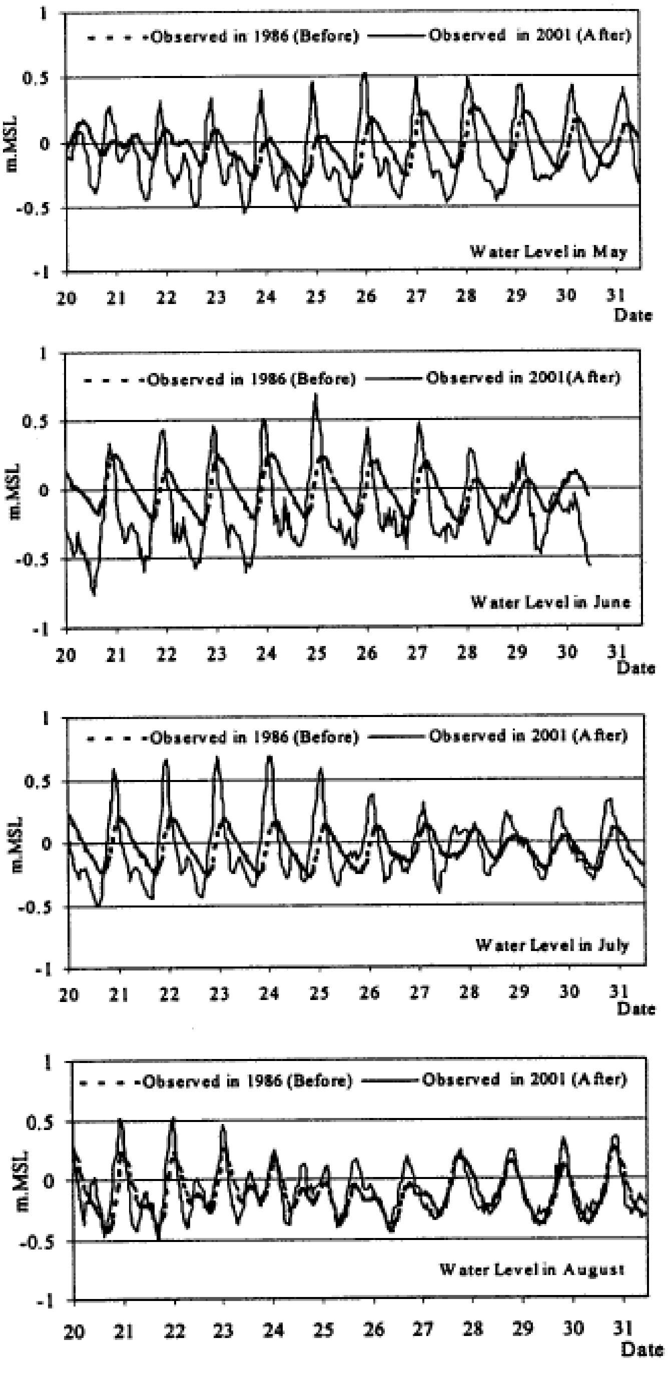
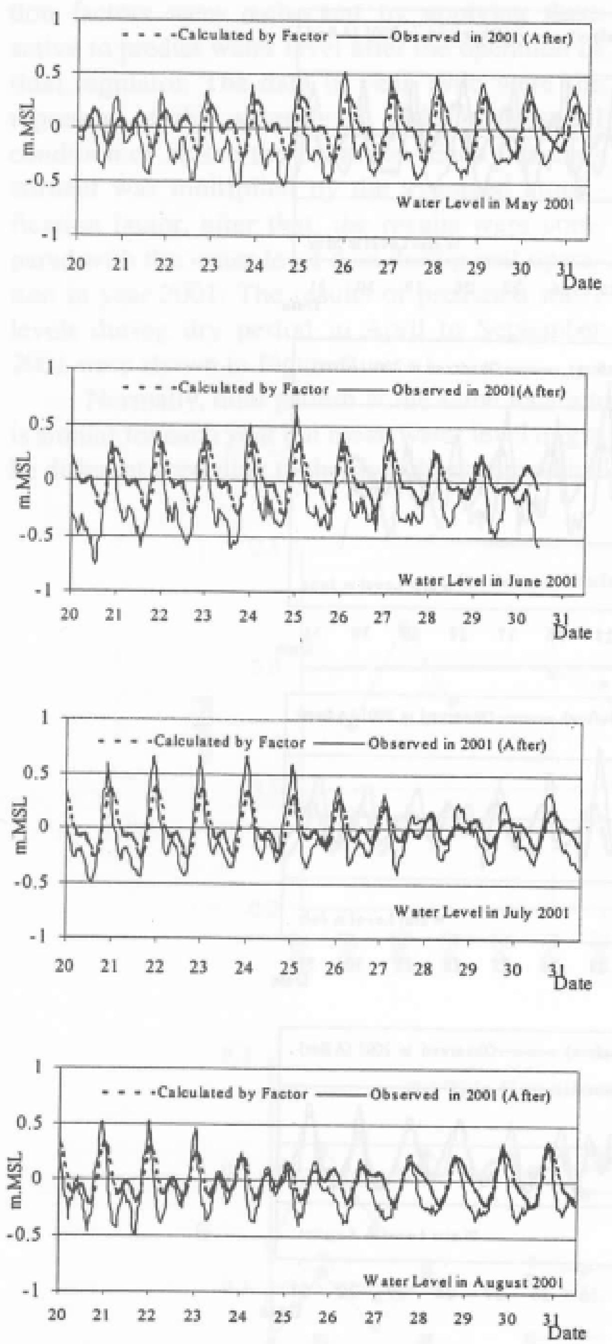


Figure 8. Water level at tidal regulator before and after operation.

of the predicted water level than the use of the averaged amplification factor in Table 6. The statistical indicators of those two approaches are shown in Table 7.

Overall results showed that the efficiency index using of averaged amplification factor in Table 6 is somewhat higher than using 2-times amplification factor whereas Root Mean Square



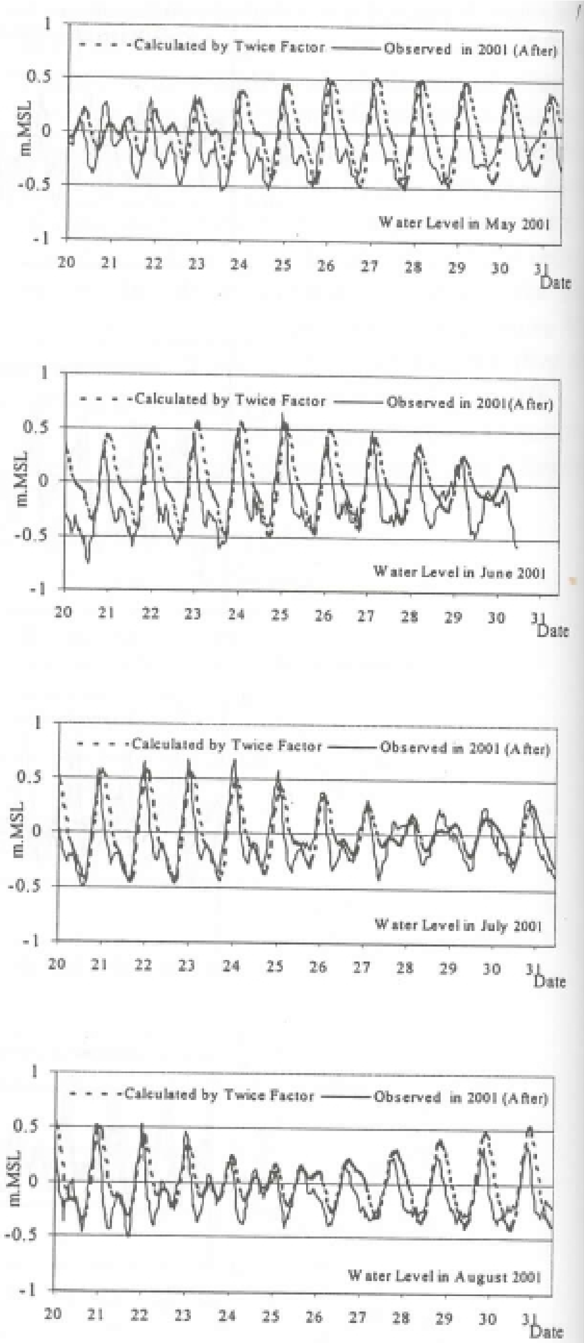


Figure 9. Predicted water level by factor in Table 6

Figure 10. Predicted water level by 2-times factor.

Error of the former is slightly less than the latter. However, the 2-times amplification factor can provide the less difference of maximum and minimum values between computed and observed water level. Thus the 2-times factor is also suitable for planning purposes for prediction of highest and lowest water level at the downstream side when the regulator is in closed operation.

Conclusion

From the study of the water level change by Tidal Regulator in the Bang Nara River, the conclusions of the important points are summarized as follows:

1. The whole year computation of water level affected by tide in the Bang Nara River could be represented well by five tide constituents which were M_2, S_2, K_1, O_1 and S_a. The tidal range in the Bang Nara River shown in Figure 3(c) is quite small, about 0.5 m and when amplified by construction of the tidal regulator would create insignificant problem. As to the water level pattern in the Bang Nara River showed a low mean water level during the middle of the year which controlled by tide constituent S_a to adjust the mean water level along the year and improve the computation results.

2. From harmonic analysis of water level data in years 1986-2001, the results of yearly analysis showed that each tide constituents were changed by a different magnitude. Semi-diurnal tides showed a greater amplification factor than the diurnal tide; the amplification factor of semi-diurnal tides M_2 and S_2 were more than 100%, about 30% for diurnal tide K_1 and about 0% for O_1.

3. Tidal regulator operation data in 2001 could be separated to two main forms of operation. During flood season, the percentage of closed operation period was around 11 and during dry season, the percentage of closed operation period was around 54.

4. From data in 2001, dry season analysis was carried out. The results showed that the tidal amplification was similar to the yearly analysis in which main semi-diurnal constituents were more highly amplified than diurnal tide constituents. Therefore, the approximated amplification factor for each tide constituent was investigated.

5. The 2-times amplification factor was introduced to represent results of water level with the assumption of permanent fully closed operation and full reflection. The computed results from 2-times amplification factor were equally as good as the approximated amplification factor in Table 6. This should be a useful tool for future calculation of water level amplification due to the construction of the regulator.

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