A COMPARSION STUDY BETWEEN THE JOINT PROBABILITY APPROACH AND TIME SERIES RAINFALL MODELLING IN COASTAL DETENTION POND ANALYSIS

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Abstract In tidally affected coastal catchments detention pond should be provided to store flood surface water. A comparison between the full simulation approach based on the joint probability method and time series rainfall modeling via the annual maximum of pond level was undertaken to investigate the assumptions of independence between variables that are necessary in the joint probability method. The rainfall data was run through a catchment model and the inflow hydrograph was obtained. This inflow was run through a detention pond with an outfall significantly affected by tidal action. The tidal variations were determined at that exact historical time of the time series rainfall. A continuous record of time series pond level was therefore determined and the peak pond level for each year was used to generate the annual maximum series of pond levels. A comparison between the growth curves of full simulation approach, and the time series rainfall modeling was undertaken. The results indicate that there are no significant differences between the two growth curves generated.

Key Words Joint Probability, Time Series Rainfall, Detention Pond, Annual Maximum Level, Tidal Level, Growth Curve

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INTRODUCTION

In general drainage authorities for industrial and residential projects have adopted a specified return period coupled with a particular storm profile and critical duration and require that the design discharge should be passed without surcharge [1,2]. In tidally affected regions, there is an added problem of the tide which affects the levels in the discharging waters. A conventional approach to the design of such system is on the probability of occurrence of rainfall and tide.

In the coastal detention pond analysis the problem was derived as a result of the development of a full simulation method based on the probability of occurrence of individual event variables, sampled from their own probability of occurrence, in order to arrive at the probability distribution of pond flood level [3]. The adoption of this philosophy seems acceptable for the design of such pondsby assumption of independence between rainfall and tide.

This study was undertaken by running the time series rainfall through a detention pond with an outfall significantly affected by tidal action. The tidal times series was generated by using sufficient harmonics to determine reasonable results. The two main constituents, the lunar and solar semidiurnal, (M2 and S2) produce realistic tidal levels, and they are adequate for the detention pond model. A continuous 30 years of pound levels were therefore determined and it was necessary to select the highest pond level for each year in order to generate the annual maximum series from the pond level time series.

Since the tide has a random nature in relation to the rainfall effect, which could be the dominant effect, it is necessary to stagger the starts of the time series rainfall in an attempt to identify any error associated with the short term tidal timing effects and also to investigate the significance of the lag effect. The staggered time series rainfall growth curves produced from annual maximum series when compared with the exact timing growth curve provided a measure of lag's significance and therefore a measure of variations that can reasonably be anticipated.

THE RAINFALL DATA

Access to rainfall data in the form of continuous time series of rainfall intensity values is necessary in order to select the best rainfall data for each practical application [4]. The best design is obtained when data from all historic rainfall events is used, combined with the necessary runoff model. The greatest problem precluding the use of historical rainfall events is the availability of adequate good data and the manipulation of the large quantities of data necessary. The rainfall data used in this study consisted of point rainfall records, linked with 12 years data at St.Mawgan and 18 years data at Rhoose, combining to form 30 years of records. The two regions are both in the South West of Britain and the length of individual rainfall records are inadequate. As a result it was necessary to concatenate the records from station within these two homogeneous precipitation regions. Since the rainfall events within this region were known to be correlated, the assumption which is implied in the case when rainfall data from different stations for the same year were concatenated is that the rainfall events recorded at one station are independent of those recorded at the other stations.

METHODOLOGY

A software program was written to generate the peak pond level in each year of the 30 years of the rainfall time series records. The input data applied in the program are the parameters for the catchment characteristics, the pond characteristics (i.e. pond bed level and storage coefficient), the outfall sewer system (i.e. outfall level elevation and discharge coefficient) and the parameters for the tidal time series. The program generates the time series rainfall data for each independent rainfall event from cumulative rainfall depth values and counts the complete data days. For runoff simulation the rainfall data is transformed to rainfall intensities with a time step of six minutes to determine the 24 hours' hyetographs. These are converted to the form of inflow hydrographs into the detention pond by considering two phases of flow, the overland phase and the pipe phase [5]. The daily inflow hydrograph, was routed through the pond and out over the simulated tidal time series. The tidal time series was generated using the year, the month, the day and the hour of the exact time that the rainfall occurred. That was generated using harmonic analysis with the two main constituent tidal effects. The pond level was determined at 6 minute intervals during the course of each day and the maximum peak pond level in each year stored.

The Extreme Value (EV) distribution is suitable for obtaining the relationship between peak pond levels and the probability of occurrence for the annual maximum series. This distribution is given by the following formula [6];

$$H = \bar{H} + k(t)\ s \qquad (1)$$

where k(t) is called the frequency factor and is a function of the return period, $\bar{H}$ is the average of all values of annual maximum pond levels, and s is the standard deviation of the values. With the mean and standard deviation of a sample of annual maximum pond level, anestimate of the pond level for any required return period can be obtained using the appropriate value of k(t).

APPLICATION

A 15ha catchment with a general site slope of 1 in 1000 together with a detention pond system of triangular section was selected with two outfall sewer levels. The sewer outfall levels were located at Mean Sea Level (MSL) and Mean High Tide Level (MHTL) for separate analyses. Since the structure of the analysis was the same for any pond shape and catchment characteristics the chosen values were not considered significant in the overall comparison. The pond was designed such that the water level was not allowed to reach the ground level at the specified 50 years design return period.

The peak pond level for each of the 30 years of rainfall data was obtained for the pond system with two separate outfall levels. These peak levels were grouped for statistical analysis and compared with the growth curves obtained using the joint probability approach.

RESULTS

Table 1 shows the annual maximum pond level and its corresponding date and time for the outfall sewer at Mean Sea Level (MSL).

The highest pond level, with a rank order of 1, is in 1959 in the St. Mawgan region. The second peak pond level is for the Rhoose area which also occurred in 1959 on the same day as the first rank. The sites are in excess of 100 miles apart and the regionalisation of the rainfall records is based on the assumption that they are sufficiently far enough away from each other that they would not suffer from the same rainfall events. Since the result of the second rank peak level is on the same day as the first peak level, it is highly likely that both events were caused by the same rainfall pattern and thus these two events are not independent. Therefore, the first event is used and the second event is rejected. As a result the first two in the ranking order are assumed as one event and the second event was not used in the table and is indicated by the asterisk. The total length of time series rainfall data is therefore reduced to 29 years of records.

The average annul maximum pond level is 3.770m with a standard deviation of 0.744. The height of pond level for the 50 year return

TABLE 1. The Different Peak Pond Levels and Plotting Positions for an Outfall at Mean Sea Level.

Name of the site	Year	Month	Day	Hour	peak pond level	sea level	Ranking order	plotting variate position	Reduced $-Ln[-Ln(1-1/T)]$	The ratio of pond level to ground level
st.Mawgan	1956	7	18	14	4.337	4.127	8	3.850	1.201	0.746
st.Mawgan	1957	9	21	16	4.195	4.157	9	3.402	1.055	0.722
st.Mawgan	1958	8	6	1	3.327	0.00	19	1.569	-0.014	0.573
st.Mawgan	1959	8	10	14	5.633	0.007	1	52	3.942	0.970
st.Mawgan	1960	8	23	20	3.799	3.882	15	2	0.367	0.654
st.Mawgan	1961	10	6	4	3.158	2.482	23	1.291	-0.399	0.54
st.Mawgan	1962	7	18	8	3.593	3.138	16	1.871	0.267	0.618
st.Mawgan	1963	8	14	15	4.578	0.00	4	8.180	2.037	0.788
st.Mawgan	1964	7	14	11	3.037	2.261	25	1.186	-0.617	0.523
st.Mawgan	1965	9	12	10	3.810	3.477	13	2.318	0.572	0.656
st.Mawgan	1966	1	23	22	3.207	2.472	21	1.416	-0.203	0.552
st.Mawgan	1967	9	24	24	2.978	2.448	26	1.139	-0.744	0.513
Rhoose	1958	7	14	7	3.168	2.259	22	1.351	-0.298	0.545
Rhoose	1959	8	10	9	5.18	2.865	*	*	*	*
Rhoose	1960	8	24	21	3.461	2.928	18	1.658	0.079	0.596
Rhoose	1961	8	10	18	3.802	3.853	14	2.147	0.467	0.654
Rhoose	1962	8	14	6	3.224	2.984	20	1.489	-0.107	0.555
Rhoose	1963	8	23	19	2.682	1.001	28	1.0566	-1.074	0.462
Rhoose	1964	7	15	10	3.481	3.209	17	1.758	0.173	0.600
Rhoose	1965	7	11	5	2.904	2.923	27	1.096	-0.890	0.500
Rhoose	1966	10	18	10	4.689	3.277	3	11.307	2.386	0.707
Rhoose	1967	5	11	9	5.024	2.940	2	18.667	2.900	0.865
Rhoose	1968	7	2	3	3.937	0.008	12	2.519	0.681	0.678
Rhoose	1969	11	8	21	4.108	0.008	10	0.046	0.921	0.707
Rhoose	1970	8	23	23	5.561	3.65	5	6.386	1.77	0.785
Rhoose	1971	8	13	12	4.362	3.781	7	4.339	1.366	0.751
Rhoose	1972	10	10	9	2.674	2.534	29	1.0196	-1.374	0.460
Rhoose	1973	8	4	11	3.047	2.714	24	1.236	-0.504	0.524
Rhoose	1974	7	2	4	4.410	1.975	6	5.237	1.552	0.759
Rhoose	1975	8	12	9	4.026	3.450	11	2.758	0.798	0.693

period is obtained as 5.70m. The 50 year pond level when compared to the results of the full simulation analysis obtained by joint probability indicates that the value is smaller by only1.97%.

Figure 1 shows the growth curve of the pond level for both the full simulation analysis and the annual maxima determined from the time Series Rainfall in the case of the outfall sewer

As the figure shows there is no significant difference between the growth curves for the joint probability method and the Time Series Rainfall modeling approach. The results indicate that for return periods approaching the 50 years value the same growth curve is obtained, whereas for the smaller return periods a small difference between the growth curves exists. For smaller return periods the growth level at MSL. The straight line obtained from the Gumbel distribution is included in the figure.

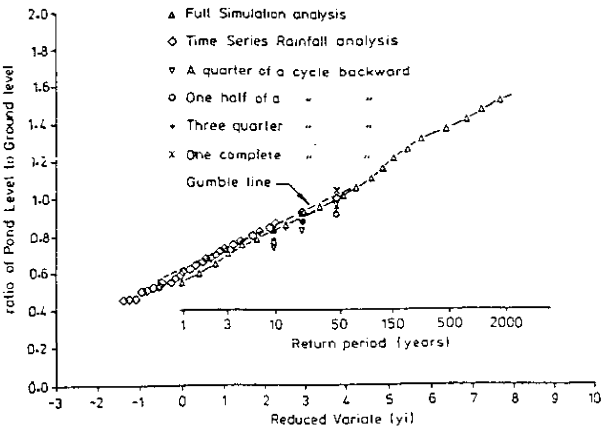

Figure 1. The growth curve of pond level for both full simulation analysis and the annual maximum level determined from the Time Series Rainfall analysis (outfall level at Mean sea level).

TABLE 2. The Different Peak Pond Levels and Plotting Positions for an Outfall at Mean High Tide Level.

Name of the site	Year	Month	Day	Hour	peak pond level	sea level	Ranking order	plotting variate position	Reduced -Ln[-Ln(1-1/T)]	The ratio of pond level to ground level
st.Mawgan	1956	7	18	9	4.905	3.240	12	2.519	0.681	0.844
st.Mawgan	1957	7	6	21	4.482	3.240	28	1.057	-1.074	0.771
st.Mawgan	1958	8	7	2	4.954	3.240	9	3.402	1.055	0.853
st.Mawgan	1959	8	10	14	5.633	3.240	1	52	3.942	0.945
st.Mawgan	1960	8	27	8	4.793	32.293	17	1.758	0.173	0.825
st.Mawgan	1961	10	6	3	4.890	3.964	15	2	0.367	0.842
st.Mawgan	1962	11	4	16	4.559	3.240	26	1.139	-0.744	0.785
st.Mawgan	1963	8	14	15	5.220	3.240	4	8.180	2.037	0.898
st.Mawgan	1964	10	9	1	4.621	3.240	24	1.236	0.504	0.795
st.Mawgan	1965	9	26	6	4.782	3.240	18	1.658	0.079	0.823
st.Mawgan	1966	10	19	10	5.171	3.863	5	6.38	1.77	0.890
st.Mawgan	1967	11	4	3	4.880	3.240	16	1.871	0.268	0.840
Rhoose	1958	10	6	10	4.990	3.240	7	4.439	1.366	0.859
Rhoose	1959	8	10	9	5.604	3.240	*	*	*	*
Rhoose	1960	8	22	6	4.716	3.922	22	1.351	-0.298	0.812
[redacted]										
Rhoose	1963	11	5	1	4.667	3.240	23	1.291	-0.399	0.803
Rhoose	1964	4	7	21	4.593	3.240	25	1.186	-0.617	0.790
Rhoose	1965	7	22	22	4.904	3.240	13	2.318	0.572	0.844
Rhoose	1966	10	18	10	5.340	3.277	3	11.375	2.386	0.919
Rhoose	1967	5	11	9	5.512	3.240	2	18.667	2.900	0.949
Rhoose	1968	7	1	2	4.974	3.240	8	3.850	1.201	0.856
Rhoose	1969	11	8	21	5.156	3.240	6	5.237	1.552	0.887
Rhoose	1970	10	11	9	4.927	3.240	10	3.046	0.921	0.848
Rhoose	1971	8	18	23	4.769	3.240	19	1.569	-0.014	0.821
Rhoose	1972	9	8	13	4.909	3.240	11	2.758	0.798	0.845
Rhoose	1973	9	16	6	4.736	3.240	20	1.489	-0.107	0.815
Rhoose	1974	9	15	9	4.893	3.240	14	2.147	0.467	0.842
Rhoose	1975	9	13	11	4.552	3.269	27	1.096	-0.890	0.783

curve obtained using full simulation was below that of obtained from using the Time Series Rainfall modeling. The smaller pond levels obtained from the joint probability method, using Intensity Duration Frequency design storms, may be due to the total rainfall volumes for the above design storms which was smaller than the total volumes using the Time Series Rainfall data [7]. It was therefore anticipated that the growth curve obtained using the full simulation approach would be generally less than those obtained using the Time Series Rainfall approach which would indicate that the two growth curves should be parallel.

Table 2 shows the highest pond levels and their corresponding date and time for the pond with the outfall at Mean High tide level (MHTL). Figure 2 details the growth curve of the pond level for both the full simulation

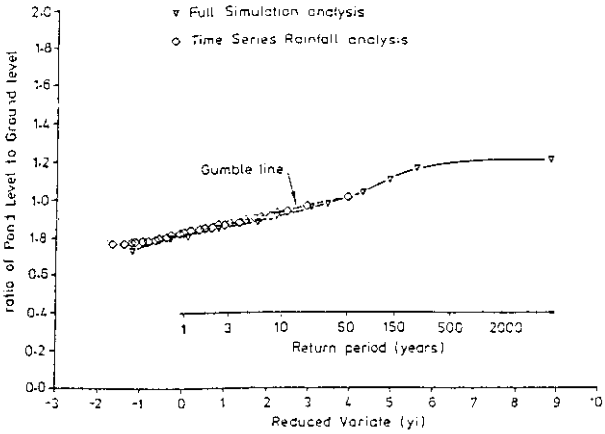

Figure 2. The growth curve of pond level for both full simulation and the annual maximum level determined by Time Series Rainfall in the case of outfall level at Mean High Tide Level.

analysis and the annual maxima determined from the Time Series Rainfall modeling.

These results also indicate that there is no significant difference between the growth curves for the pond levels obtained from the two distinct approaches. The average maximum annual level of the pond obtained by the Time Series Rainfall approach is 4.887m. This value when compared with the average pond level based on the full simulation method gives an increase of 1.03%. The height of the pond level for the 50 years return periods 5.63m. This level when compared to the results of the full simulation indicates a decrease of 3.0%.

THE RAINFALL-TIDE CORRELATION

In this paper a study was undertaken in which the Time Series Rainfall coincided exactly with the actual tidal elevation at that time in that year. So, any correlation of causative parameters that exist in reality but were assumed independent in the joint probability approach are naturally included in the Time Series Rainfall analysis. As a result it is necessary to stagger the starts of the Time Series Rainfall. If the timing of the system is offset by a quarter or half a cycle, all of the existing correlations will remain intact. This is because the correlations between variables are considered to be of a larger time scale. The new growth curve in comparison with the previous growth curve produces a measure of the importance of the lags and will allow a limited determination of the overall tidal significance. The similarity between the growth curves would indicate that the tide and particularly the lag effect is not significant, whereas different growth curves would give a strong indication that the tide is infact a dominant affect.

Four different tidal offsets at quarter, half, three-quarter and a full cycle in the case of an outfall sewer elevation at Mean Sea Level (MSL) were undertaken for the first three peak pond levels in the analysis. Table 3 shows the value of pond level sets for these three cases.

Each ordinate of the peak pond levels represent the value for the corresponding cycle. As expected a comparison between the 0 and 360 phase lags (one complete cycle) shows the rank of the peak levels to be the same. The variation in levels is only a result of the amplitude difference and because the two tides have similar heights similar levels are presented. The rank for the quarter and half cycle lags are the same. The ranks of the peak levels for the three-quarter cycle phase lags are, however, different. Table 4 shows the mean value, standard deviation and coefficient of variation of the pond levels for different phase lags for those three peak pond levels.

To clarify the results and to investigate in detail whether the tide is significant, it is necessary to consider the actual variation of the pond level and sea level with respect to time. The first peak pond level in the case of the outfall sewer level at Mean Sea Level (MSL) was selected for this study. Figure 3 shows these variations from 36 hours before to 36 hours after the peak pond level for the five different tidal starting times. As Figure 3-I shows the initial rise in pond level occurs whilst the tide is out. As the tide comes in, the rain stops, and the level drops almost to sea level, it then continues to rise to a peak level at 5.633m. After this peak the pond level drops rapidly due to continuing discharge in the tide free period and becomes almost empty at the start of the next tide locked period.

Figure 3-II shows that as the tide starts a quarter cycle later a similar pond level profile is

TABLE 3. Peak Pond Levels for Different Phase Lags for the Three Most Extreme Events (Outfall Level at Mean Sea Level).

Name of the catchment site	Year	Month	Day	Hour	peakpnond level(m)	sea levelv(m)	Ranking order	Phase lag
st.Mawgan	1959	8	10	14	5.633	0.00	1	Time to Time
Rhoose	1967	5	11	09	5.024	2.94	2	
Rhoose	1966	10	18	10	4.698	3.277	3	
st.Mawgan	1959	8	10	15	5.798	2.555	1	A quarter cycle beckward (3.105 hours)
Rhoose	1967	5	11	09	4.254	0.00	2	
Rhoose	1966	10	18	10	3.284	0.00	3	
st.Mawgan	1959	8	10	14	4.910	0.862	1	one half cycle backwrd (6.21 hours)
Rhoose	1967	5	11	09	4.706	0.00	2	
Rhoose	1966	10	18	10	3.249	0.00	3	
st.Mawgan	1959	8	10	08	5.327	2.81	1	three quarter cycle backward (9.315 hours)
Rhoose	1967	5	11	09	4.191	1.691	3	
Rhoose	1966	10	18	10	4.718	3.989	2	
st.Mawgan	1959	8	10	14	5.800	0.00	1	one conplet cycle backward (12.42 hours)
Rhoose	1967	5	11	09	5.180	2.269	2	
Rhoose	1966	10	18	10	4.700	1.361	3	

TABLE 4. Mean, Standard Deviation and Coefficient of Variation of the Different Peak Pond Levels for the Three Extreme Events.

Rank order	peak to peak	one quarter cycle	one half cycle	Three quarter cycle	one complete cycle	Average value of peaks	standard deviation	Coefficient of variation
1	5.633	5.798	4.910	5.327	5.800	5.49	0.337	6.14%
2	5.024	4.254	4.706	4.191	5.180	4.671	0.397	8.505%
3	4.689	3.284	3.249	4.718	4.700	4.128	0.704	17.04%

obtained. In this case the initial rain is almost emptied from the pond before the second main rainfall arrives; this rainfall exists entirely within the tide locked period and a higher peak is obtained at 5.789m when compared to that of Figure 3-I.

A similar result on storage level profile is presented in Figure 3-III. This figure is for the case of a complete half cycle where the peak pond level is substantially lower. The storage level profile in the case of the three-quarter-cycle offset is presented in Figure 3-IV. As the figure shows, since the tide locked period occurs, a small peak pond level is achieved. The peak pond level obtained in the final stage is 5.800 m and shows the highest level. Here the timings are exactly the same as the ones shown in Figure 3-I excepting that the tide would be higher and thus would produce a higher pond level. The tides are clearly moving from springs to neaps during the event.

The difference in level achieved through the cycle and the difference between complete cycles gives a measure of the tidal influence on this system. Clearly a significantly higher level would be achieved at a spring tide.

The value of pond level sets for different tidal phase lags for the three first extreme events areshown in the growth curve of Figure 1. As the figure indicates, there is no significant difference between the different growth curves.

CONCLUSION

In this paper, a comparison between the full

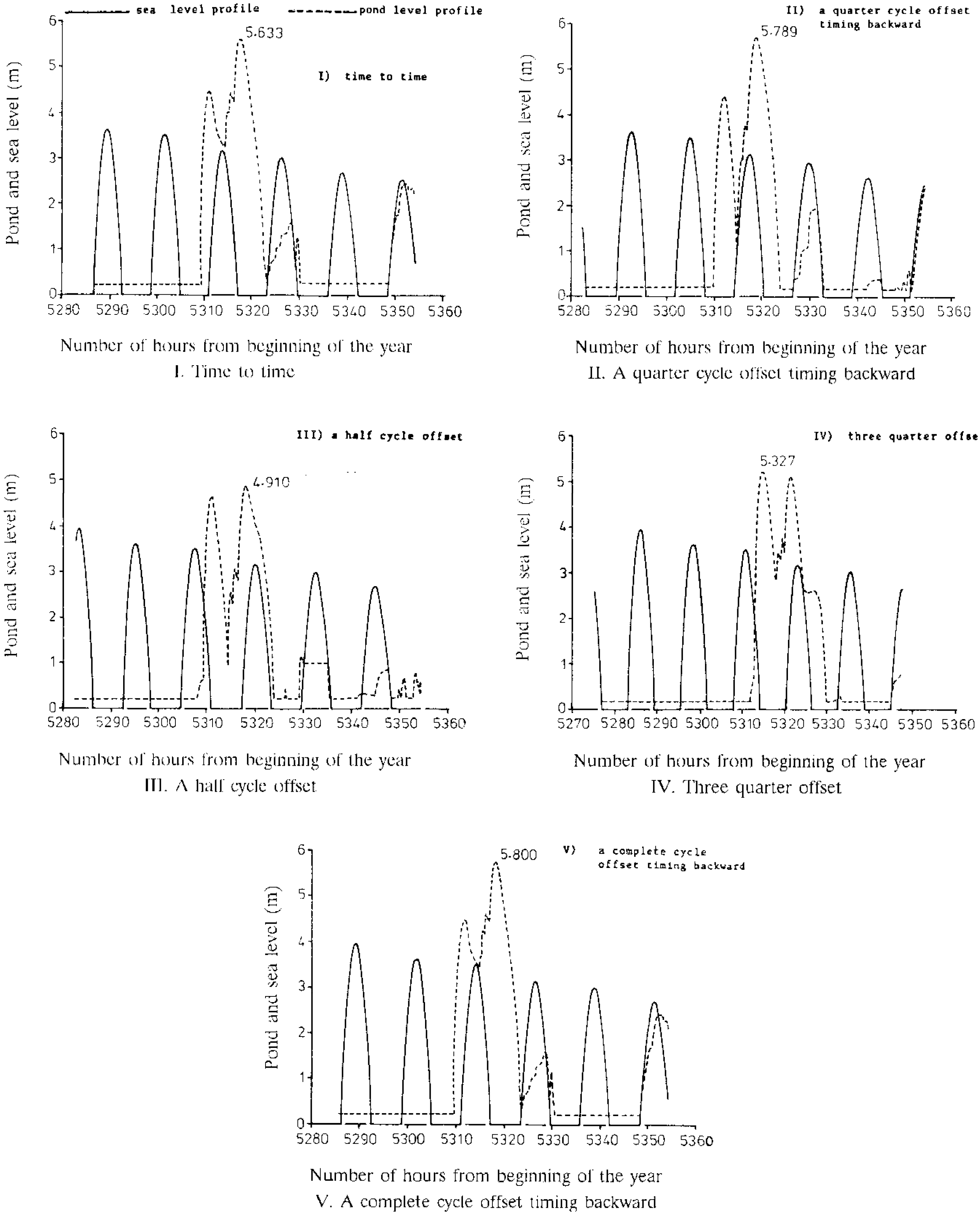

Figure 3. The pond level and sea level profile for 36 hours before and 36 hours after the peak level in the case of 5 different tidal cycles.

simulation approach based on the joint probability method and Time Series Rainfall modeling via annual maximum level was undertaken. Two different kinds of rainfall data have been used in the investigation :

I- Rainfall data estimated from Intensity Duration Frequencyrelationship, together with distributions obtained from statistical sampling, and II- Time Series Rainfall data from 30 years of records.

The entire rainfall data was run through the catchment and the inflow hydrograph was generated. This inflow hydrograph was then run through the pond model to generate the effect of the actual tide series at that exact historical time. The pond level time series is therefore determined during the course of each day and the maximum peak pond level in each year was finally obtained. The growth curve obtained from the annual maximum levels was plotted. The result indicated that there are no significant differences between the growth curve for full simulation based on the joint probability approach, and the growth curve obtained from the Time Series Rainfall modeling analysis. For smaller return period the growth curve obtained by the Time Series Rainfall lies slightly above that obtained using the full simulation approach but this is not considered significant.

The pond level obtained by using The Time Series Rainfall is theoretically more accurate but it seems likely that the design simulation which is based on the full simulation analysis, can be used with little error. The design simulation approach has the advantage of being easy and in expensive to use, whereas the Time Series Rainfall approach is clearly more expensive and complicated.

In an effort to identify any problem associated with the lag and to investigate the significance of the tide effect the start of the Time Series Rainfall was staggered. Four different start points were allocated for the first three ranked peak pond level events. The result showed that the rainfall was a more significant than either the size of the tide or the lag. The results indicated that, within the limitation of the model, the assumption of no correlation between the tide and rainfall event is reasonable.

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