RESEARCH NOTE

SELECTION OF DESIGN EVENTS IN TIDALLY AFFECTED DETENTION POND SYSTEMS

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Abstract In this paper the development of a single set of design parameters of the sizing of the tidally affected detention pond system was analysed and tested. The approach uses critical duration single storm event of specified return period, together with a single harmonic tide. The design flood level is then the aggregate of the levels obtained using the system model with the four phase lags between the high tide and peak inflow. The inequality resulting between the return period of the storm and the resulting aggregate level is adjusted using a modeling factor. The modeling factor is seen to vary significantly with the level of the offsite sewer and this variation is quantified.

Key Words Detention Pond, Flood Return Period, Peak Pond Level Return Period, Modeling Factor ,Design Storm

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INTRODUCTION

In designing detention ponds with tidal and rainfall influence, to store flood surface water, it is necessary to give guidance to the designer on the selection of tides and storms that should be used in the design of these ponds. In their inland detention pond systems, drainage authorities have, in general, adopted a specified return period coupled with particular storm profile and critical duration and require that the design discharge should be passed without surcharge. In tidally affected coastal regions, there is an added problem of the tide which affects the levels in the discharging waters. In such areas the same standards for rainfall input variables are adopted and the simulation method is developed based on deriving the joint probability of occurrence of detention pond by combining the probability of the rainfall and peak tidal amplitudes [1]. Since designers will be unable, for economic reasons, to run all the combinations of tide and rainfall used in the full simulation process, it is necessary to give guidance to the designer on the selection of tides and storms that should be used in the design of these ponds.

The normal method of design for drainage systems is based on an estimation of the design flood discharge, with the specified storm duration together with the storm profile. It is normally assumed that the return periods of the peak discharge and the design storm are equal. The equality may be approximated by setting all other design inputs, i.e.the variables that are significant to the derivation of the design hydrograph which must be specified by the designer, at their median values [2].

A more objective choice of the design inputs on rivers, may be obtained by means of sensitivity analysis in which the design method is applied repeatedly with different combinations of their probabilities of occurrence [3]. The selection of the design storm is based on rainfall depth intensity-duration-frequency information and a catchment response model.A simulation technique is described which samples the possible ways in which a T-year rainfall return period can cause floods, and derives their probability distribution.It was considered that the median values of storm duration and storm profile yield a design flood not far removed from the average flood following the T-year storm.

Later the Flood Studies Report also suggested selecting design storm parameters, for estimating floods in rivers, through a sensitivity analysis to find the antecedent conditions and design storm that consistently gave flows which matched observed flood frequency distributions [4]. Since there was rarely enough data to define an observed flood frequency distribution, it was considered that a synthetic flood frequency distribution may have to be used. This distribution was generated by the simulation method in probability space. The catchment model was run with many different combinations of input variables sampled in proportion to their own probabilities of occurrence in order to obtain a probability distribution of the output. Four design inputs were proposed for the flood estimation, a representative value being allocated to three of them. The fourth value was then specified to generate the equality between the rainfall return period and the flood peak discharge return period. The four design inputs consisted of the total depth, duration of rainfall, the storm profile and a measure of antecedent conditions, in the form of a Catchment Wetness Index (CWI).

Packman and Kidd investigated the relationship between the probabilities of hydrological variables in urban drainage design [5]. The objective of the investigation was to determine systematically a suitable set of input variables for the selection of the design storm event which will, on the average, produce a peak runoff of the required return period. They suggested that the synthetic flood frequency distribution should be generated through a continuous simulation, by feeding a long rainfall record through the rainfall-runoff model, calibrated to the particular catchment area, rather than the probability simulation used in the Flood Studies Report. This approach was used because the probability simulation requires more analysis and correspondingly a much larger computer resource. As a result of the sensitivity analysis, to variations in design inputs, the following definitions were found for the hydrological variables [6];

I) The storm duration should be the one which gives the maximum peak flow discharge.

II) The return period of the rainfall depth should be equal to that of the peak runoff.

III)The storm profile should be the "50% Summer" profile.

As a result, if a storm rainfall of T-year return period with the 50% summer profile over each of the durations of 15, 30, 60 and 120 minutes are applied to the model, the T-year flood for the catchment will, on the average, be the maximum peak flow obtained from these durations.

METHODOLOGY

The normal method of design for drainage system is based on estimation of the design flood discharge, with the specified return period. In coastal drainage analysis, it is necessary to obtain a design flood level using rainfall depth duration, frequency together with tidal variations and a catchment response model. In order to perform statistical hydrological analysis to determine an economic design flood, it is necessary to compare floods of varying duration, profile, return periods and at various states of tide with the overall simulation results. The simulation results considered are, within the limitations of the modeling procedure, assumed, to be the "correct" results. The approach is then to select "appropriate" values for the different design variables so that the peak design flood level should approach the flood level obtained from full simulation.

This process achieved by designing a pond, using the full simulation analysis for the T-year level, and then using T-year design rainfall and comparing the flood depth to the design level for average causative events as previously used in inland catchments. It may then be possible to determine a relationship between the storm rainfall return period and pond flood return period. This relationship introduces a modeling factor and the variation of this modeling factor can be investigated to determine whether it is related to site specific data.

Current practice is to use inland design storms with extreme tides and at their extreme worst position [7]. Clearly this event will have a return period greatly in excess of the design storm. The selected method somehow allows this design to account for extreme events to be included in the process, without generating unduly over-conservative designs. The philosophy behind the approach adopted is to use existing average events following existing inland systems, to allow the designer to undertake extreme events in relation to the tide but to have these averaged out with less extreme events where possible and, finally, to generate a relationship between rainfall and event return period to cover any inequality developed.

I. The Selected Return Period In the tidally catchment drainage design there are two return periods to be considered: the rainfall return period and the tidal return period. The T-year tide return period will never cause the T-year level in the detention ponds since if it is not raining the pond is going to be empty. It is necessary, therefore, to concentrate the analysis on trying to generate a rainfall return period equal to the pond level return period. Since detention pond are dominated by the rainfall return period, the logical approach is to ignore the tidal using the peak probability distribution concept. The specification of the design flood should be determined by the designer following an economic appraisal.

II. The Selected Storm Profile For a given storm duration and total rainfall, there is an infinite variety of storm profiles, the variation for which is caused by the different rainfall types. The storm profiles were ranked according to their peak intensity [8].The published profiles were for 10%,25%,50%,70% and 90% Summer and Winter peakedness, defined as the ratio of maximum to mean intensity. Since most of the short storms occur in the summer, it is preferable to use a summer profile in the analysis. Because the "50% Summer" profile is the average profile, in that 50% are less or more peaked, it is most natural to consider it as a single design event in storm drainage design. However, the "75% Winter" profile is recommended for river catchment studies.

Although the 50% summer profile seems appropriate for urban drainage and the 75% winter profile can be justified for fluvial flows, they will provide confidence to the designer than provide an advantage for the benefit of selecting an ideal design event.

III. The Selected Storm Duration A design storm is a sequence of rainfall intensities of a defined total duration. Real recorded rainfalls could be adopted as a design storm, but in most systematic design methods it is common to specify some simple characteristics of the storm which lead to a calculated sequence of rainfall intensities. The duration required for storm drainage cannot be defined accurately. In using a uniform intensity method,an average rate of rainfall of a given return period over a series of durations equal to the time of concentration, is recommended. Studies with the hydrograph methods have shown that the storm duration which produces the maximum discharge is usually larger than the time of concentration [9].

Wooldridge proposed that for the design of storage tanks larger durations than those giving the peak discharge are required [10]. In the current study, the considered durations cover all rain storm durations, from 1 hour to 48 hours,that are commonly selected in river flooding design. For urban drainage design it would be preferable to have a large number of durations in the range of 30 minutes to 6 hours to produce the real relationships between the critical duration and catchment characteristics. However, such data is not available. In reality the designer is always likely to change the design duration which is considered necessary to allow the designer the flexibility of this parameter in the design. In the current study a range of storm duration is considered within the model with the design duration set at any part which produces the peak pond level. That is, even the worst duration can be used as a suitable stable value for the design event.

IV. The Selected Tide Amplitude The probability density of peak tidal level was synthesized where the tidal variation is dominated by the principal lunar and solar semidiurnal constituent tides. The value of Mean High Tide Level (MHTL) is equal to the summed product of each High Tide level and its corresponding relative frequency. The most logical selection of a single value of tidal amplitude as the design event is a tide equal to MHTL. This is because it is the average tide value and easy to determine. The single design tide is, however, a drastic simplification of tidal behavior. If the outfall level is above the MHTL, then the selection of MHTL as a single tidal effect is not reasonable. The reason is that in such a case there is no tidal effect and the model and detention pond are effectively tide free. It is necessary, therefore, to refine the MHTL by introducing the average representative tidal level called the Mean Level of Tidal Exceedence as a design event.

V. The Selected Number of Lags Between Peak Inflow and High Tide The position in the tidal cycle is specified as the phase lag between the peak inflow into the pond and the arrival time of high tide. It is not reasonable to select one lag as the design basis. The reason is that by selecting one lag, it would have to be an average lag which means that the tide would be half in or half out. In this case, if the outfall sewer level is high,the analysis may be entirely nontidal which is an unrealistic event. The selection of two lags is possible, but does not really adequately cover the range of events. Therefore, four lags were adopted because they reasonably cover the range and represent the random nature of coincidental occurrenec of tidal levels to peak inflow into the pond. This has the advantage of averaging the four different cases,high tide coinciding with peak inflow,low tide and with the tide just crossing the Mean Sea Level (MSL) both at rising and falling states. The probability of occurrence of the phase lag was dependent on the total number of lags selected in the analysis.

MODELING FACTOR

The initial design methodology provided a basis for recommending the particular design values for the different parameters. All the fixed variables have been selected which included the rainfall design return period, the 50% Summer storm profile, the worst storm duration, the mean tidal amplitude, and four phase lag positions in the tidal cycle. It is proposed to run these design events at two different return periods and compare the peak design flood level with the flood level obtained from the full simulation analysis. This process is undertaken by first designing a pond using the full simulation analysis for the T-year level. Then running the T-year design rainfall with the above design event parameters. Using this design event level for the pond and the return period that has already been achieved by full simulation analysis, the design event level can be determined. It is, therefore, possible to use this process to introduce a modeling factor defined as the ratio of these two return periods. The variation of this modeling factor can then be investigated to determine whether it is related to site specific data.

APPLICATION

Table 1 indicates the significant parameter variables, that affect the system. By considering all of those variables, that affect the system, 96 different modeling factor were obtained for the pond and catchment selection by using the ratio between design rainfall return period and resulting pond level return period. Since all of the single design variables have been selected on approximately average values and only the duration variable is based on the worst duration, it would, therefore, be expected that the average value of the modeling factor would be less than one.

TABLE 1. Parameter Variable Values Used in the Parametric Study.

	Catchment Characteristics		Pond Characteristics		Tide Characteristics	
Name of Variable	Area of Catchment	Slope of Catchment	Pond Shape	Outfall Elevation	Tidal Amplitude	Design Return Period
No. of Selected Variables	2	2	2	3	2	2
Values of Variables	15 ha 500 ha	0.001 0.002	Triangular Rectangular	MSL,MHWN MHTL	Location 1 Location 2	20 years 50 yeaes
	i=1; 15 ha i=2; 500ha	j = 1; 0.001 j = 2; 0.002	K=1;Triangular K=2;Rectangular	1=1,MSL 1=2;MHWN 1=3;MHTL	m=1;Avonmouth m=2;Aberdeen	n = 1; 20 n = 2; 50

TABLE 2. Values of Modeling Factor for 20 Year Return Period Using Mean High Tide Level (MHTL) as the Design Tide.

g 2,1,1,1,1,1 = 0.784	g 1,1,1,1,1,1 = 0.815
g 2,1,1,3,1,1 = 0.541	g 1,1,1,3,1,1 = 0.571
g 2,1,2,1,1,1 = 0.842	g 1,1,2,1,1,1 = 0.785
g 2,1,2,3,1,1 = 0.526	g 1,1,2,3,1,1 = 0.557
g 2,2,1,1,1,1 = 0.760	g 1,2,1,1,1,1 = 0.670
g 2,2,1,3,1,1 = 0.488	g 1,2,1,3,1,1 = 0.445
g 2,2,2,1,1,1 = 0.870	g 1,2,2,1,1,1 = 0.784
g 2,2,2,3,1,1 = 0.490	g 1,2,2,3,1,1 = 0.560
g 2,1,1,2,1,1 = 0.476	g 1,1,1,2,1,1 = 0.458
g 2,1,2,2,1,1 = 0.604	g 1,1,2,2,1,1 = 0.528
g 2,2,1,2,1,1 = 0.503	g 1,2,1,2,1,1 = 0.465
g 2,2,2,2,1,1 = 0.618	g 1,2,2,2,1,1 = 0.604
g 2,1,1,1,2,1 = 0.840	g 1,1,1,1,2,1 = 0.820
g 2,1,1,3,2,1 = 0.640	g 1,1,1,3,2,1 = 0.572
g 2,1,2,1,2,1 = 0.910	g 1,1,2,1,2,1 = 0.889
g 2,1,2,3,2,1 = 0.665	g 1,1,2,3,2,1 = 0.556
g 2,2,1,1,2,1 = 0.823	g 1,2,1,1,2,1 = 0.784
g 2,2,1,3,2,1 = 0.570	g 1,2,1,3,2,1 = 0.667
g 2,2,2,1,2,1 = 0.950	g 1,2,2,1,2,1 = 0.870
g 2,2,2,3,2,1 = 0.586	g 1,2,2,3,2,1 = 0.516
g 2,1,1,2,2,1 = 0.588	g 1,1,1,2,2,1 = 0.580
g 2,1,2,2,2,1 = 0.618	g 1,1,2,2,2,1 = 0.600
g 2,2,1,2,2,1 = 0.538	g 1,2,1,2,2,1 = 0.628
g 2,2,2,2,2,1 = 0.606	g 1,2,2,2,2,1 = 0.590

TABLE 3. Values of Modeling Factor for 50 Year Return Period Using Mean High Tide Level (MHTL) as the Design Tide.

g 2,1,1,1,1,2 = 0.774	g 1,1,1,1,1,2 = 0.810
g 2,1,1,3,1,2 = 0.550	g 1,1,1,3,1,2 = 0.550
g 2,1,2,1,1,2 = 0.926	g 1,1,2,1,1,2 = 0.840
g 2,1,2,3,1,2 = 0.671	g 1,1,2,3,1,2 = 0.692
g 2,2,1,1,1,2 = 0.787	g 1,2,1,1,1,2 = 0.760
g 2,2,1,3,1,2 = 0.586	g 1,2,1,3,1,2 = 0.560
g 2,2,2,1,1,2 = 0.900	g 1,2,2,1,1,2 = 0.855
g 2,2,2,3,1,2 = 0.635	g 1,2,2,3,1,2 = 0.565
g 2,1,1,2,1,2 = 0.625	g 1,1,1,2,1,2 = 0.556
g 2,1,2,2,1,2 = 0.698	g 1,1,2,2,1,2 = 0.630
g 2,2,1,2,1,2 = 0.633	g 1,2,1,2,1,2 = 0.570
g 2,2,2,2,1,2 = 0.671	g 1,2,2,2,1,2 = 0.635
g 2,1,1,1,2,2 = 0.908	g 1,1,1,1,2,2 = 0.880
g 2,1,1,3,2,2 = 0.675	g 1,1,1,3,2,2 = 0.665
g 2,1,2,1,2,2 = 0.865	g 1,1,2,1,2,2 = 0.895
g 2,1,2,3,2,2 = 0.695	g 1,1,2,3,2,2 = 0.714
g 2,2,1,1,2,2 = 0.893	g 1,2,1,1,2,2 = 0.806
g 2,2,1,3,2,2 = 0.610	g 1,2,1,3,2,2 = 0.616
g 2,2,2,1,2,2 = 0.926	g 1,2,2,1,2,2 = 0.927
g 2,2,2,3,2,2 = 0.641	g 1,2,2,3,2,2 = 0.625
g 2,1,1,2,2,2 = 0.655	g 1,1,1,2,2,2 = 0.670
g 2,1,2,2,2,2 = 0.678	g 1,1,2,2,2,2 = 0.687
g 2,2,1,2,2,2 = 0.658	g 1,2,1,2,2,2 = 0.602
g 2,2,2,2,2,2 = 0.662	g 1,2,2,2,2,2 = 0.590

RESULTS

A statistical analysis is undertaken to obtain the relationship between various values of modeling factor and the values of the different parameters. Table 2 and Table 3 show different values of modeling factor for the 20 year and 50 year design return period, respectively. The modeling factor is subscripted as g_{ijklmn} where different values of indices are explained in Table 1.

The mean, standard deviation and coefficient of variations of the modeling factor for each variable have been computed and tabulated separately in Table 4 and Table 5 for 20 year and 50 year design return periods, respectively. In general, the results indicate that the sensitivity of the modeling factor to change in the catchment area, to catchment site slope, and to shape of the pond and tidal amplitude is not materially significant in determining the modeling factor. The average modeling factor is more sensitive to the outfall sewer elevation relative to the sea level, for both return periods than for all other variables. The deepening of the outfall level from Mean High Tide Level (MHTL) to Mean High Tide Neap (MHTN) and then to Mean Sea Level (MSL) increases the modeling factor by 0.7% and 47.8 for 20 year return period and 2.7% and 36.76% for 50 year return period, respectively. There is only a slightly increased modeling factor, moving the outfall sewer level from MHTL to MHWN, whereas from MHWN to MSL there is a

TABLE 4. Mean, Standard Deviation and Coefficient of Variation for Each of the Catchment Parameters (20 Year Return Period) in the Case of MHTL as a Design Tide.

Name of Variable	Variable Value	Mean Modeling Factor for All Variables	Standard Deviation	Coefficient of Variation %	Standard Deviation and Coefficient of Variation for Different Value of Each Variable	
Area (ha)	15 500	0.638 0.661	0.1303 0.1465	20.50 22.18	0.0114	1.75
Shape of the Pond	Triangular Rectangular	0.626 0.673	0.1294 0.1451	20.64 21.57	0.234	3.60
Slope of the Catchment Site	1 in 1000 1 in 500	0.657 0.642	0.1358 0.1425	20.67 22.20	0.0074	1.14
Location of the Tide	Higher Tide Lower Tide	0.614 0.685	0.1347 0.1350	21.93 19.72	0.03515	5.40
Outfall Level	MSL MHWN MHTL	0.826 0.563 0.595	0.0677 0.0571 0.0595	8.20 10.14 10.64	0.1250	19.25

considerable increase. The coefficient of variation of the average modeling factors for the case of the three different outfall levels is 19.25% and 14.82% for 20 year and 50 year return period respectively. As a result, over the range of different variables considered, the modeling factor is only materially related to the outfall sewer elevation rather than to the other site parameters.

Figure 1 shows the variation of the modeling factor with the outfall for the 20 year and 50 year return periods, together with the 90% and 95% confidence limits.

By considering the position of the outfall level in relation to the tidal condition, it is possible to determine the modeling factor, and therefore, to obtain the specified flood return period .The figure provides reasonable bands for defining the exact rainfall return periods in relation to the flood return period. This can be used to directly determine the required storm return period for different outfall sewer elevations relative to the local tidal condition.

Figure 2 shows the direct relationship between the chosen design return period and the storm return period. This enables the flood level return period to be chosen for recommended rainfall return periods for different outfall level positions relative to the sea level. This allows the designer to obtain the design flood for any required return period and outfall level position relative to the local tidal situation.

CONCLUSION

The main objective of this paper was to develop

TABLE 5. Mean, Standard Deviation and Coefficient of Variation for each of the Catchment Parameters (50 Year Return Period) in the Case of MHTL as a Design Tide

Name of Variable	Variable Value	Mean Modeling Factor for All Variables	Standard Deviation	Coefficient of Variation %	Standard Deviation and Coefficient of Variation for Different Value of Each Variable	
Area (ha)	15 500	0.706 0.720	0.1223 0.115	17.32 16.00	0.0076	1.10
Shape of the Pond	Triangular Rectangular	0.684 0.738	0.112 0.114	116.35 15.50	0.0270	3.80
Slope of the Catchment Site	1 in 1000 1 in 500	0.722 0.700	0.111 0.112	15.45 17.13	0.0108	1.50
Location of the Tide	Higher Tide Lower Tide	0.687 0.735	0.1147 0.1129	16.69 15.37	0.0238	3.35
Outfall Level	MSL MHWN MHTL	0.859 0.645 0.628	0.055 0.038 0.053	6.40 5.90 8.40	0.1050	14.82

a single set of design parameters for a storm runoff detention pond discharging into a tidal sea. A suitable design event was determined that enabled a simple design analysis to be undertaken that represents the results of full simulation over a range of catchments, detention ponds, tidal situations and return periods. This approach which is as simple as possible allows the designer to properly consider alternative designs without the need for excessive calculations.

It was accepted, as a prerequisite, that the full simulation produces the "correct solution". It was, therefore, necessary to select suitable single values for each variable to form a design event. The selection was being undertaken as a result of comparisons with the full simulation process. A summary of the findings was as follows;

I) The storm duration should be such that it gives the maximum peak pond level.

II) The profile should be the "50% Summer" profile.

III) The selection of a single value of the tidal

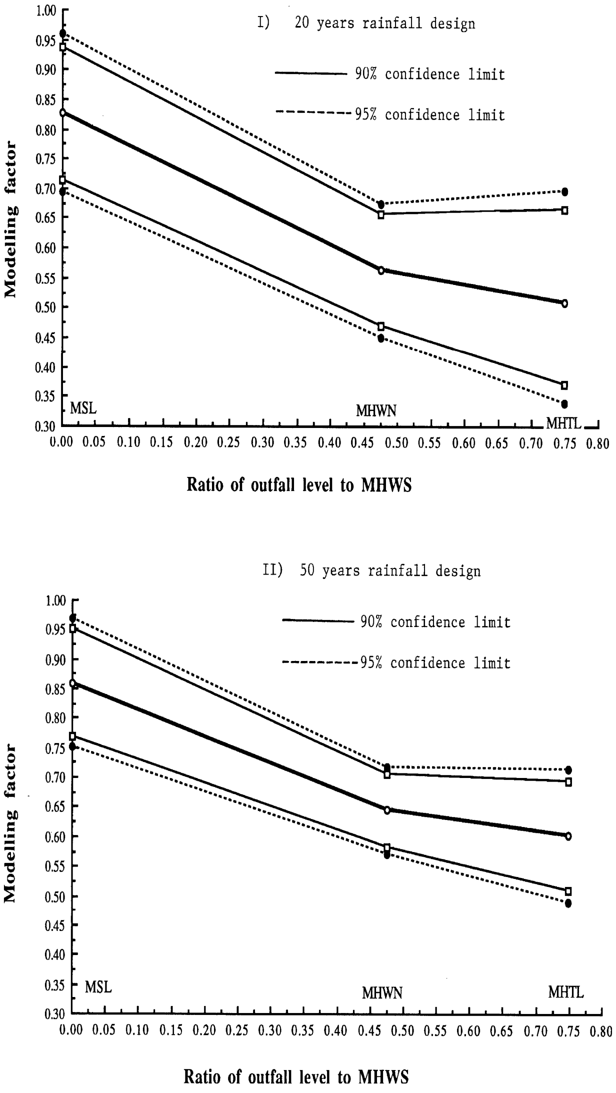

Figure 1. Variation of modeling factors with outfall level including confidence intervals: (I) 20 yesr and (II) 50 year return period.

amplitude is equal to MHTL.

IV) The selection of four lags between the peak inflow and peak tidal level.

Based on these design events a modeling factor, defined as the ratio of the full simulation return period and the design return period, was introduced. The effect of different site parameters on that factor was investigated and it was concluded that, over the range of different parameters considered, the most significant variable was the outfall sewer elevation. By considering the position of the outfall level in relation to the tidal condition it is possible to determine the expected value of the modeling factor and therefore the appropriate rainfall return period in relation to the flood level return period in the design analysis.

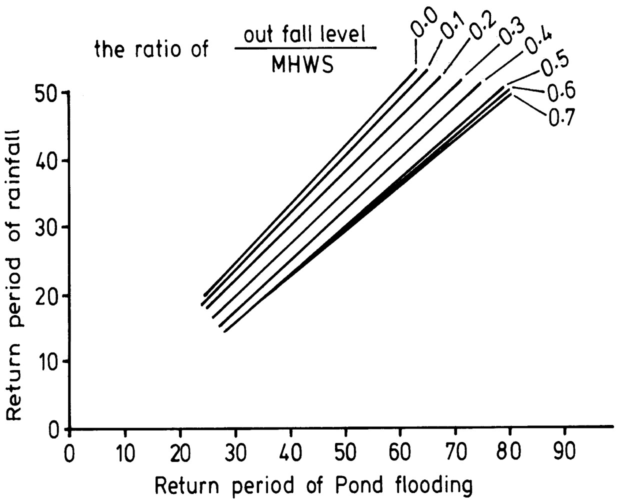

Figure 2. Variation of flood return period with rainfall return period for different outfall levels.

REFERENCES

1. Hughes, T. G. and Gorji-Bandpy, M., "The Analysis of Surface Water Detention Ponds for Tidally Affected Drainage Outfalls", ***Proc. Instn. Civil. Engrs., Water, Maritime and Energy***, No. 124, (1997), 201-211.
2. Cordery, I., "Estimation of Design Hydrographs for Small Rural Catchments", ***J. Hydrology***, No. 13, (1971), 263-277.
3. Bran, M. A., "Estimation of Design Flood and the Problem of Equating the Probability of Rainfall and Runoff", ***UNESCO-WMO-IAHS Conf. on Design of Water Resources Project with Inadequate Data, Madrid***, Vol. 2, (1973), 459-471.
4. Institute of Hydrology, "Hydrological Studies; Flood Studies Report", England, Vol. 1, (1993), 24-37.
5. Packman, J. C. and Kidd, C. H. R., "A Logical Approach to the Design Storm Concept", ***Water Resources Research***, No. 16, (1980), 994-1000.
6. National Water Council, "Design and Analysis of Ubran Storm Drainage", The Wallingford Procedure, England, Vol.1, (1981), 45-51.
7. Shalandan, M. J., Riley, M. J. and Toswell, P., "The

Impact of Climate Change on Maritime Local Drainage Authorities Aspects", ***Proc. Instn. Civil. Engrs. Mun. Engr.***, No. 109, (1995), 120-127.

8. Institute of Hydrology, "Meteorological Studies; Flood Studies Report", England, Vol. 2, (1993), 1-32.
9. Bran, M. A., "Hydrological Aspects of Combined Effects of Storm Surges and Heavy Rainfall on River Flow", W.M,O. Operational Hydrology Report, Sweden, No. 30, (1988), 12-19.
10. Wooldridge, G., "Storage Tanks in Storm Drainage Systems", ***Hydraulic Research***, Wallingford, England, Report No. 227, (1982), 25-29.