TECHNICAL NOTE

A PARAMETRIC STUDY FOR IDENTIFICATION OF THE VARIABLES IN TIDALLY AFFECTED POND SYSTEMS

M. Gorji-Bandpy

Department of Mechanical Engineering, University of Mazandaran
Babol, Iran, gorjibandpy@yahoo.com

(Received: January 5, 1997 - Accepted in Revised Form: May 4, 2000)

Abstract In this paper a parametric study was undertaken to quantify the sensitivity to a wide range of coastal detention pond systems dealing with tidal influence to store surface flood water so as to produce general guidance on the importance of the catchment and pond variables. In this process a specified pond design return period was selected for which the system was to be designed. The pond volume was determined as the fundamental design criterion in the statistical analysis for all the different modeling combinations. The results showed that over the range of different variables for the pond volume identification, the most significant variables were the catchment area and the pond location, as incorporated in the analysis via the size of tidal amplitudes adopted. The sensitivity of the system to the outfall sewer level and its realistic position relative to the sea level was investigated.

Key Words Detention Pond, Ground Level, Full Simulation, Mean Sea Level, Tidal Amplitude

³½ »¦eBw ·¥B®« nj »d¤w ºB´IIC ºn°Céª] ºÃoII »î±®~« ºBµ³aB¼nj »eÃo¥ nj »´¦Th« ¥«Ã±î **²k¼ña**
jB\Ç¼A ³ÇII ¢±IIoÇ« jkíT« ºBµoT«ÃnBQ ³II ¥«Ã±î Ë¼A /k®®½»« S§Bij ,jnÃj nÃo¹B¼nj k« ° nq] o¼UFU SdU B¼nj JC
ºÃoÇII ¨p¿ ©\Çe ,¥Ç«Ã±î Ë¼A pA ºjAkíU ËTµo£o¨¯ nj BII ³§B¸« Ë¼A nj /k¯nAj »¢TvII »IIC ¶p±e ð½ º°n JÀ¼w
»¯BÇ«p ºBµ²n°j nj ³¦Th« ºB´§k« ËT i Bw ºÃoII »wBwA nB¼í« ° ¾B®L« ð½ ¬Ã±®íII »î±®~« ºBµ³aB¼nj »eÃo¥
B¼nj c¤w ³II SLv¯ ¥eBw c¤w ¨±¹n³II »¢TvII ³½ ³aB¼nj ©ª¼q½B« ·ªî ° ²k¼jo£»eÃo¥ ¤Bw 50 ° 20 } hz«
©\Çe BµoTÇ«ÃnBQ Ë¼A t BwA oII ³½ jkíT« ºBµoT«ÃnBQ ¬B¼« pA ³½ kµj»« ¬Bz¯ [½BT¯ /k¼C»« SwkII ,jnÃj ³¸¤®« nj
BÇII ¢BLÇUnA nj ³aBÇ¼nj »¯Bñ« S¼í¹±« ° B¼nj ¥eBw nj é¹A° q¼oIIC ¶p±e SeBv« ¥«Bî °j ,jjo£»« ¤k« ³aB¼nj
JC »]°o i ·§±§ BII ¢BLUnA nj ¤k« S¼wBve /k®Tvµ »eÃo¥ ¥«Ã±î Ë¼oTª´« pA ,³¸¤®« nj B¼nj k« ªB´UnA oX½ÃÃke
»ÇeÃoÇ¥ B¼nj JC c¤w ³II SLv¯ ³§±§ Ë¼A ·¼¹j S¼í¹±« ° ²k¼jo£ »wnoII jq¼n»« B¼nj ³II ³¼¦hU ºÃoII ³½ ³aB¼nj
/jjo£»«

INTRODUCTION

In general, two groups of variables, rainfall and tide, affect the design of a storm water runoff detention pond system located below the elevation of commonly occurring high tides and discharging into the sea by gravity. Some of these groups are fixed, these include catchment and rainfall characteristics, Mean Sea Level (MSL), and the tidal characteristics. The other parameters that include size, shape, location of the pond, and the offsite sewer characteristics, are to be designed. The primary purpose of the parametric study is to identify all relevant parameters that allow for the reasonable coverage of all pond types, sizes and locations.

Due to the complexity of the relationships between various design parameters in the tidally affected ponds, the optimum physical characteristics for any pond system are difficult to determine. It is necessary to undertake a complete set of pond designs for each combination of parameters and investigate the effect of each parameter on the design of the pond and the response of the system. Whenever possible, it is necessary to relate different parameters to each other to reduce the number of variables. Reduction must be based on reasonable considerations that are unlikely to influence the overall relative respsonse but to allow parameter variation to be retained. The choice of parameter variation depends on a reasonable consideration of the likely range of values found in the field. When unrelated variables are uncorrelated, then the numerical calculation of regression equations and interpretation of their coefficient would be simple.

METHODOLOGY

The first step to determine the relationships between the parameters is to list all of the parameters that influence the system and determine the effect of the parameters on the overall system performance. The parameters are divided into two groups: variable and fixed. All independent parameters are to be tested with all combinations of unrelated parameters. Table 1 lists all the different groups of variables that influence the system. These variables were selected so as to include all parameters that might be of significance in the modeling of the pond system. However, it is not possible to treat all of them independently.

In designing the coastal detention pond volume, the designer needs estimates of the probability that the pond water level does not exceed adjacent Ground Level at the given return period. This level is generally considered so high that the tide level will not reach it and the maximum allowable water level will be governed by that level. To determine the relationship between the parameters and quantify the sensitivity to different variables, the following procedure was adopted; A specified pond design return period of T-year was selected for which the system was designed. An estimated value of the pond volume was selected. The full simulation was undertaken based on 12 storm durations, 10 storm return periods, 10 storm profiles, 8 peak tidal amplitudes and 4 different tidal phase lags, and the growth curve for pond level was obtained. These are the suitable vehicle to investigate pond system design [1]. The return period corresponding to the Ground Level was noted. If it was not equal to the one originally envisaged, a new pond volume value was selected. This process was repeated on an intelligent trial and error basis until the value of the required pond volume corresponding to the T-year return period pond level (as Ground Level) was obtained. The pond volume that produces this height was, therefore, computed for all different modeling combinations. The mean and standard deviation of the pond volume for each of the variables were computed for each return period separately to determine the dependence of the modeling on different variables and to obtain the sensitivity of the whole system to each variable.

RAINFALL CHARACTERISTICS

The magnitude of the rainfall events is based on the method detailed in the Wallingford Procedure [2]. The twelve storm durations considered were of 1,3,6,9,12,15,18,21,24,30,36 and 48 hours with their own probability distribution. The necessary rainfall return periods and the corresponding representative rainfall return periods for the parametric study and the requirement to reasonably model the drainage system can be computed using methods previously detailed [3].

TABLE 1. List of All Different Groups of Variables that Influence the System.

Characteristic Groups	Name of Variables
Catchment and Rainfall	1. Catchment site area 2. Catchment site general slope 3. Percentage runoff a. Soil Index b. Urban Catchment Wetness Index (UCWI) C. Percentage of Impervious Surface 4. Rainfall a. M5-2 day (total rainfall of return period 5-year and duration 2 days) b. $r = \left(\frac{M5\text{-}60min}{M5\text{-}2day}\right)$, M5-60min (total rainfall of return period 5- year and duration 60 minutes) 5. Areal Reduction Factor (ARF)
Pond and Outfall Sewer	1. Pond shape 2. Pond bed level 3. Pond design return period 4. Ground level 5. Offsite sewer length 6. Offsite sewer gradient 7. Offsite sewer diameter 8. Offsite sewer roughness 9. Offsite sewer outfall level
Tidal	1. Mean Sea Level 2. Tidal amplitude variation 3. Peak inflow and high tide phase lag

The ten storm profile shapes chosen were the Summer 10%, 30%, 50%, 70%, and 90% and the Winter 10%, 30%, 50%, 70%, and 90%.

Two catchment areas are considered in the study: a small area (i.e. 15 ha) and a larger area (i.e. 500 ha) for comparison. The explicit value of the inflow hydrographs and the pipe size necessary to carry these discharges into detention pond without surcharging within these two catchments can be obtained [4]. As a result, the diameters of 400 mm and 1500 mm were obtained for the 15 ha and 500 ha areas, respectively.

Two different catchment slopes of uniform gradient of 0.001 and 0.002 were selected for comparison of the analysis. These were considered to be reasonably representative of coastal catchment.

DETENTION POND CHARACTERISTICS

Two different configurations of the pond were chosen for comparison. These were triangular and rectangular ponds of prismatic section. Detention ponds can be generally of any shape but these two are considered to represent reasonable limits. The shape, is therefore, defined as the power to which the pond depth is raised in determining the pond volume. The pond volume is assumed to take the form of:

$S = Csto\ (H\ pond - H\ min)^2$ for triangular section

$S = Csto\ (H\ pond - H\ min)^1$ for rectangular section

Where (H pond - H min) is the storage height, S is the storage volume and Csto is the storage coefficient. In the case of triangular pond, Csto is equal to $\frac{L}{\tan a}$, L is the length of the pond and a is the slope of the pond side. In the case of rectangular pond, however, Csto is equal to the pond surface area. Two distinct return period values of 20 years and 50 years were selected for the parametric study. The former representing interests of a normal return period in smaller catchments and smaller open channel drainage systems whereas the latter represents the return period of main rivers and coastal engineering works.

Two different offsite pipe slopes of 0.001 and 0.002 were considered in connection to the catchment slope. The offsite pipe is assumed to be laid at the uniform catchment slope. It is necessary to design the outflow sewer pipe to suit the size of the system where consistency between catchment size, pipe size and detention pond size should exist. As a result, the outfall pipe diameter was assumed to be the same as the diameter of the inflow sewer pipe into the pond in a free outfall condition. This is due to the assumption of the same gradient in the inlet and outflow sewer pipes. In the design of detention ponds with tidal influence, the selection of outfall level depends on both the tidal and rainfall behaviors. For inland pond systems with a free surface outfall, steeper pipes increase the outflow discharge of the system. In the design with tidal submergence it is necessary to design the system to cater for the tide, which is in, during part of the cycle, the absolute minimum outfall level being determined by the sea bed level.

In order to prevent the obstruction of the discharge due to the accumulation of silt and sedimentation, the range of outfall levels between sea bed level and Mean Sea Level is not generally recommended for gravity system. As a result, the outfall sewer was considered to coincide with three different outfall elevations: Mean Sea Level (MSL), Mean High Water Neap (MHWN) and Mean High Tide Level (MHTL).

TIDAL CHARACTERISTICS

The probability density of peak tidal level was synthesized where the tidal variation is dominated by the principal lunar and solar semidiurnal constituent (M2 and S2) tides.

Two different ports with substantially different tidal variations were selected for comparison. The proposed areas were Aberdeen and Avonmouth, in the United Kingdom, the former with lower solar and lunar tidal amplitudes (i. e. 0.445 m and 1.302 m respectively), which the latter with significantly higher tidal amplitudes (i. e. 1.50 m and 4.25 m respectively) [5]. The values of Mean High Water Spring (MHWS) and Mean High Water Neap (MHWN) are 5.75 m and 2.75 m for

TABLE 2. Frequency Distribution of Peak Tidal Amplitudes (I) Avonmouth and (II) Aberdeen.

(I) AVONMOUTH

High tide mid range level in (m)	2.9375	3.3125	3.6875	4.0625	4.4375	4.8125	5.1875	5.5625
Average number of occasions per year	133	65	59	57	58	66	81	186
Probability of the level in the range indicated (%)	18.865	9.220	8.369	8.085	8.227	9.362	11.489	26.383
Cumulative probability %	18.865	28.085	36.454	44.539	52.766	62.128	73.617	100

(II) ABERDEEN

High tide mid range level in (m)	0.9126	1.0238	1.1355	1.2462	1.3574	1.4686	1.5798	1.6910
Average number of occasions per year	133	65	59	57	58	66	81	186
Probability of the level in the range indicated (%)	18.865	9.220	8.369	8.085	8.227	9.362	11.489	26.383
Cumulative probability %	18.865	28.085	36.454	44.539	52.766	62.128	73.617	100

Avonmouth and 1.747 m and 0.857 m for Aberdeen, respectively.

Table 2 represents the frequency distribution of peak tidal amplitude divided up into 8 intervals. These are derived from a timestep of a 6 minutes for the height predictions, which is considered sufficiently accurate to predict the peak tide level. The tables are illustrated graphically in Figure 1. It is clear that the most probable levels are near Mean High Water Neap (MHWN) and Mean High Water Spring (MHWS). The value of (MHTL) is equal to the product of each High Tide Level and its relative frequency. These values for Avonmouth and Aberdeen are 4.283 m and 1.312 m respectively.

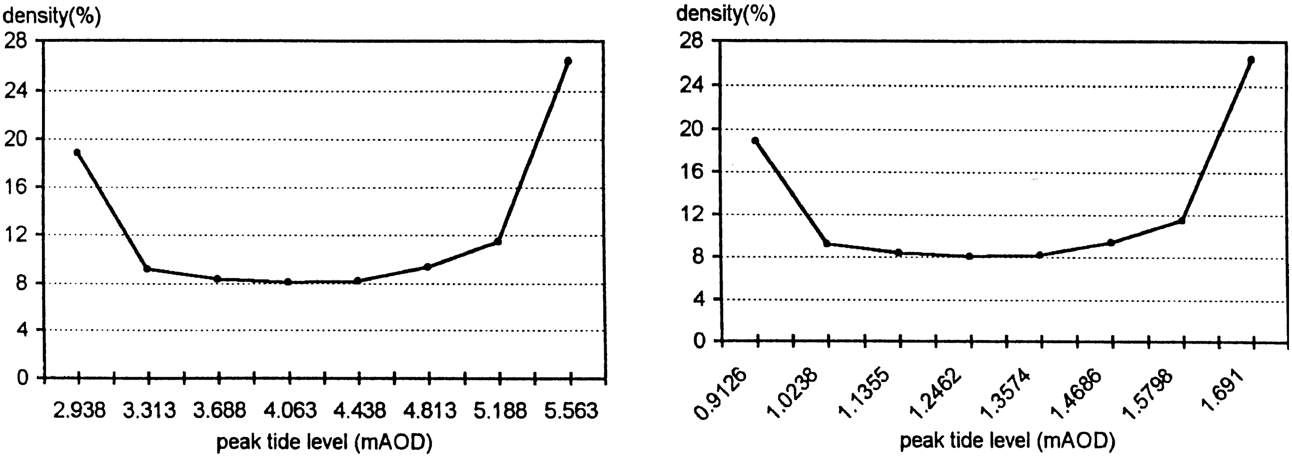
The probability of occurrence of the phase lag between high tide and peak inflow hydrogaph is dependent on the total number of lags selected for full simulation and was assumed to be representative of an equal interval of time in the cycle. Four tidal phase lags are adopted in the parametric study.

TEST RUN

The full simulation analysis was conducted using equivalent systems at the two different specified rainfall return periods of 20 years and 50 years with the return period pond water level as the Ground Level. Table 3 lists different groups of parameters that were varied for the whole system and the values selected. By considering all the variable values that affect the system 48 different pond volumes were obtained for each specified return period.

RESULTS

Table 4 and Table 5 show the values of pond volumes for each different analysis. The pond



(a) (b)

Figure 1. The probability density distribution for 8 different tidal amplitudes (a) Avonmouth and (b) Aberdeen.

TABLE 3. Parameter Variable Values Used in the Parametric Study.

	Catchment Characteristic		Pond Characteristics		Tide Characteristics	
Name of Variable	Area of Catchment	Slope of Catchment	Pond Shape	Outfall Elevation	Tidal Amplitude	Desig Return Period
No. of Selected Variables	2	2	2	3	2	2
Value of Variable	15 ha 500 ha	0.001 0.002	Triangular Rectangular	MSL MHWN MHTL	Location 1 Location 2	20 years 50 yeaes
	i= 1; 15ha 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

volumes are introduced by Vijklmn where the variable values corresponding to each of the indices are shown in Table 3. The mean, the standard deviation and the coefficient of variation of the pond volumes for each variables are presented in Table 6 and Table 7 for 20 year and 50 year design return period, respectively.

The results indicate that,

I) The pond volume is very sensitive to the catchment area.

II) By changing the triangular section pond to

TABLE 4. Pond Volumes (m^3) Resulting from the Combined Event for 20 Year Return Period.

Area of catchment(500ha)	Area of catchment(15ha)
V2,1,1,1,1,1 = 40500	V1,1,1,1,1,1 = 1370
V2,1,1,3,1,1 = 40460	V1,1,1,3,1,1 = 1345
V2,1,2,1,1,1 = 48900	V1,1,2,1,1,1 = 1590
V2,1,2,3,1,1 = 47800	V1,1,2,3,1,1 = 1570
V2,2,1,1,1,1 = 39570	V1,2,1,1,1,1 = 1320
V2,2,1,3,1,1 = 35700	V1,2,1,3,1,1 = 1300
V2,2,2,1,1,1 = 48630	V1,2,2,1,1,1 = 1560
V2,2,2,3,1,1 = 44600	V1,2,2,3,1,1 = 1500
V2,1,1,2,1,1 = 40480	V1,1,1,2,1,1 = 1350
V2,1,2,2,1,1 = 48000	V1,1,2,2,1,1 = 1580
V2,2,1,2,1,1 = 35950	V1,2,1,2,1,1 = 1310
V2,2,2,2,1,1 = 45700	V1,2,2,2,1,1 = 1520
V2,1,1,1,2,1 = 62400	V1,1,1,1,2,1 = 1820
V2,1,1,3,2,1 = 62000	V1,1,1,3,2,1 = 1900
V2,1,2,1,2,1 = 70600	V1,1,2,1,2,1 = 2200
V2,1,2,3,2,1 = 65300	V1,1,2,3,2,1 = 2065
V2,2,1,1,2,1 = 60600	V1,2,1,1,2,1 = 1900
V2,2,1,3,2,1 = 57000	V1,2,1,3,2,1 = 1750
V2,2,2,1,2,1 = 68000	V1,2,2,1,2,1 = 2110
V2,2,2,3,2,1 = 61100	V1,2,2,3,2,1 = 1920
V2,1,1,2,2,1 = 62100	V1,1,1,2,2,1 = 1910
V2,1,2,2,2,1 = 65750	V1,1,2,2,2,1 = 2040
V2,2,1,2,2,1 = 57750	V1,2,1,2,2,1 = 1770
V2,2,2,2,2,1 = 61900	V1,2,2,2,2,1 = 1880

TABLE 5. Pond Volumes (m^3) Resulting from the Combined Event for 50 Year Return Period.

Area of catchment (500ha)	Area of catchment (15ha)
V2,1,1,1,1,2 = 61550	V1,1,1,1,1,2 = 1920
V2,1,1,3,1,2 = 24400	V1,1,1,3,1,2 = 1860
V2,1,2,1,1,2 = 70960	V1,1,2,1,1,2 = 2225
V2,1,2,3,1,2 = 64950	V1,1,2,3,1,2 = 1905
V2,2,1,1,1,2 = 61250	V1,2,1,1,1,2 = 1915
V2,2,1,3,1,2 = 53300	V1,2,1,3,1,2 = 1700
V2,2,2,1,1,2 = 69600	V1,2,2,1,1,2 = 2200
V2,2,2,3,1,2 = 60700	V1,2,2,3,1,2 = 1900
V2,1,1,2,1,2 = 54450	V1,1,1,2,1,2 = 1900
V2,1,2,2,1,2 = 68250	V1,1,2,2,1,2 = 2070
V2,2,1,2,1,2 = 53650	V1,2,1,2,1,2 = 1700
V2,2,2,2,1,2 = 66100	V1,2,2,2,1,2 = 2000
V2,1,1,1,2,2 = 84480	V1,1,1,1,2,2 = 2600
V2,1,1,3,2,2 = 79000	V1,1,1,3,2,2 = 2400
V2,1,2,1,2,2 = 92820	V1,1,2,1,2,2 = 2850
V2,1,2,3,2,2 = 85700	V1,1,2,3,2,2 = 2600
V2,2,1,1,2,2 = 82450	V1,2,1,1,2,2 = 2520
V2,2,1,3,2,2 = 75000	V1,2,1,3,2,2 = 2280
V2,2,2,1,2,2 = 89800	V1,2,2,1,2,2 = 2780
V2,2,2,3,2,2 = 78200	V1,2,2,3,2,2 = 2370
V2,1,1,2,2,2 = 79400	V1,1,1,2,2,2 = 2440
V2,1,2,2,2,2 = 87850	V1,1,2,2,2,2 = 2710
V2,2,1,2,2,2 = 75700	V1,2,1,2,2,2 = 2300
V2,2,2,2,2,2 = 82200	V1,2,2,2,2,2 = 2500

TABLE 6. Mean, Standard Deviation and Coefficient of Variation of Parameter Variables for a 20 Year Return Period.

Name of Variable	Variable value	Mean pond volume for all variables	Standard deviation	Coefficient of variation %	Standard deviation and coefficient of variation for different value of each variable	
Area (ha)	15 500	1690 52950	277 10790	16.38 20.38	25629	93.81
Shape of the pond	triangular rectangular	25569 29071	25199 28091	98.55 96.63	1751	6.40
Slope of the catchment site	1 in 1000 1 in 500	28130 26510	27467.5 25970	97.60 97.60	810	2.97
Location of the tide	Higher tide Lower tide	22233 32407	21048 30585	94.70 94.40	5087	18.60
Outfall level	MSL MHWN MHTL	28323 26940 26692	27756 26319 26066	96.00 97.70 97.88	718.3	2.63

one of rectangular section, the pond volume increases by 13.7% and 12.5% for 20 years and 50 years design return period, respectively. The triangular section ponds seemed slightly more efficient than the rectangular ponds. This is expected because a triangular pond would always discharge more than a rectangular pond with the same volume and the water will always be deeper.

III) The pond volume is smaller with steeper catchment sites and steeper outflow sewer pipes than with flatter sites. This is because flattening the outflow pipe (or lowering the pond bed elevation) limits the length of the time that discharge from the pond is restricted by the high tide. Therefore the total pond volume for a specified return period will increase. Doubling the gradient of the catchment results in a decrease of 6.1% and 4.3% in the pond volume for 20 years and 50 years design return period, respectively.

IV) The average pond volume in lower tidal amplitudes is larger than for the higher tidal amplitudes. This shows a 45.8 % and 34.1% increases for 20 year and 50 year design return period, respectively.

V) By deepening the outfall sewer level, the pond volume will increases. This is because discharge, which is not permitted during the tide locked period, is being stored throughout the

TABLE 7. Mean, Standard Deviation and Coefficient of Variation of Parameter Variables for a 50 Year Return Period.

Name of Variable	Variable value	Mean pond volume for all variables	Standard deviation	Coefficient of variation %	Standard deviation and coefficient of variation for different value of each variable	
Area (ha)	15 500	2227 72177	347.77 12019.20	15.59 16.65	349.75	94.0
Shape of the pond	triangular rectangular	35020 39385	12019.2 37748	97.00 95.93	2182.4	5.87
Slope of the catchment site	1 in 1000 1 in 500	37984 36421	36785.6 35166.3	96.85 96.55	2781.15	2.10
Location of the tide	Higher tide Lower tide	31782 42623	30196.4 40065	95.01 94.00	5420.30	14.57
Outfall level	MSL MHWN MHTL	39495 36565 35548	37915 34737 33593	96.00 95.00 64.50	1673.3	4.50

period and hence the pond volume will increase. The deeper the outfall pipe is submerged below the sea level, the longer the tide locked period and the duration that the discharge is restricted by the high tide, resulting in a larger pond volume. By deepening the outfall sewer level from Mean High Tide Level (MHTL) to Mean High Water Neap (MHWN) and Mean Sea Level (MSL) the average pond volume will increase by 0.9% and 6.1% for the 20 years return period and by 2.86% and 11.1% for the 50 years return period ponds.

The results, however, show only a slightly higher pond volume in moving from MHTL to MHWN outfall level than from MHWN to MSL outfall level. This increased volume is 0.9% and 5.13% for a 20 years design return period and 2.9% and 8% for a 50 years design return period respectively. As a result there is not much of a benefit in using a sewer higher than the MHTL in order to reduce the pond volume. The realistic outfall levels lie in the range between MHWN and MHTL. The effect of three variables, catchment slope, outfall sewer pipe level and shape section of the pond are not materially significant. The coefficient of variation of the pond volume for the catchment area and the tidal amplitudes are 94% and 15% for 50 yeaes return period and 93.8% and 19% for 20 years return period. The system is considered sensitive to these two parameters which are both prescribed variables and is not within the control of the designer.

CONCLUSION

The main objective in the design of coastal detention ponds dealing with tidal influence is to provide guidance to the designer on a limited number of tides and storms that should be used in designing the pond. A parametric study was undertaken to quantify the sensitivity to a wide range of detention pond systems so as to produce general guidance on the relative importance of the catchment and pond parameters. A complete set of pond designs for each combination of variables was undertaken and the effect of each parameters on the design of the pond and the response of the system was investigated.

The results show that over the range of different variables for the pond volume study the most significant variables are the catchment area and the location, as represented in the size of the tidal variation. The system is sensitive to the outfall sewer level, by deepening the outfall sewer the pond volume will increase. The realistic outfall level lies in the range between Mean High Water Neap (MHWN) and Mean High Tide Level (MHTL).

REFERENCES

1. Hughes, T. G. and Gorji-Bandpy, M., "The Analysis of Surface Water Detention Ponds for Tidally Affected Drainage Outfalls", ***Proc. Inst. Civil Engrs.***, Water, Maritime and Energy, No. 124, (1997), 202-211.
2. National Water Council, "Design and Analysis of Urban Storm Drainage", The Wallingford Procedure, England, Vol. 1, (1981), 31-34.
3. Institute of Hydrology, Hydrological Studies; Flood Studies Report, England, Vol. 1, (1993), 12-23.
4. Sarginson, E. J. and Nussey, B. B., "The Explicit Computation of Urban Runoff", ***Proceeding of the First Internationl Seminar, Southampton, England***, (1982), 2.25-2.32
5. Royal Navy Hydrographer, Admiralty Tide Tables, United Kingdom, Vol. 1, (1997), 55-73.