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Peak Factors for Sewerage System in Upper Egypt Communities

معاملات الذروة لمنظومة الصرف الصحي في مجتمعات صعيد مصر

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KEYWORDS:
Peak flow
Sewers
Pumping stations
Wastewater treatment plants
Small communities

***الملخص العربي*:- مُعامل الذروة (PF) هو النسبة المئوية لأقصي تصرف إلى متوسط التصرف اليومي في مياه الصرف الصحي حيث يتم تقدير كل من القيمة المتوسطة والحد الأقصى للتصرف اليومي بشكل عشوائي بسبب وجود بعض التباين في قيمهما. في هذه الدراسة تم تطوير معادلات معامل الذروة لمناطق الدراسة المختلفة في صعيد مصر مع تعدادات مختلفة للسكان واستهلاكات مختلفة للمياه حيث تم تجميع عشر سنوات من بيانات التصرف وقياسها لمناطق الدراسة وتحليلها لتطوير معادلة P.F. وتمت مقارنة قيم التصرف وقيم P.F التي تم الحصول عليها من المعادلات المستنتجة في المناطق التي شملتها الدراسة بالدراسات السابقة.**

***Abstract*:-The peak factor (PF) is the proportion of the maximum flow to the average daily flow in a wastewater system. Both of the average and the maximum daily flow are evaluated randomly because there is difference in their values, therefore the corresponding peak factor (PF) may be explained based on a probabilistic theory. In this study, Peak factor equations were developed for different studied areas in Upper Egypt region with different populations and water consumption. Ten years of flow data was collected and measured for the study areas and analyzed to improve the P.F equation. The flow values and P.F values acquired from the developed equations of the studied communities were compared to equations from previous studies.**

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I. INTRODUCTION

THE flows in sanitary wastewater systems change with time. The design of sanitary wastewater systems depends on the conception of the amount and fluctuation of these flows. Using a dimensionless peaking factor (PF) is the common method to estimate the peak flow. The PF is the proportion of the maximum flow to the average daily flow. (Zhang, X., et al. 2005).

Flow in the sewers of small community results from irregular usage of a range of home devices, each with its own characteristics. At the outfall, the noticed flow in the sewer is usually continuous and tends to have repeated daily patterns. As the sewer network becomes larger, flows from the various branches join and tend to even out the flow change. Therefore, flow variability declines as the population rises. (Imam, E., et al. 2014).

The wastewater composed through the gravity sewer network in small community served commonly by one or two lifting pump station to the treatment plant. The capacity of pumps, the hydraulic design of the sump, and the operation of the pumping station emerge the inflow hydrograph reaching the treatment plant. Therefore, the peaking factors given by the design codes for sewer flow may not be used identically in the design of the particular units of the treatment plant. Several equations are improved to evaluate peak flow factors.

The common variables that control most of these equations are the population and the average daily flow. Empirical methods are often used for determining the PF in a sanitary sewage system. Metcalf 1935, presented a PF diagram that remains at 4 when the population is less than five thousand, and decreases logarithmically when the population exceeds five thousand (Tchobanoglous, et al. 2003). Johnson 1942 also presented a PF diagram that is well approximated with the following Equation:-

$$PF_1 (P) = \frac{5.2}{P^{0.15}} \quad (1)$$

Where P is population in thousands.

The well-known Harmon formula, included in Recommended Standards for Sewage Works by the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers, is given as (Harmon 1918)

$$PF_2 (P) = 1 + \frac{14}{4 + \sqrt{P}} \quad (2)$$

The Babbitt form, usually utilized in the wastewater systems is expressed as (Babbitt and Baumann 1958)

$$PF_3 (P) = \frac{5}{P^{0.2}} \quad (3)$$

Using data from (Metcalf 1935), (Johnson 1942) and (Gifft 1945) revised the Babbitt equation as shown below:

$$PF_4 (P) = \frac{5}{P^{0.167}} \quad (4)$$

John Gaines, chief planning engineer of Denver's wastewater management division, developed the following equation:-

$$P.Fmax = 6.66 \times Qavg^{-0.168} \quad (5)$$

Ben moltoun form, usually utilized in the wastewater systems is expressed as (Moulton 1999)

$$P.Fmax = 2.71\ Q^{-0.119} \quad (6)$$

Where the flowrates ranged from 80 to 85 gpcd.

Equation (2) is recommended by Egyptian code to be used in case of population more than 80,000 and equation (4) for population less than 80,000.

These empirical equations for evaluating the wastewater peaking factors limited by a specific population ranging from 1000 to 1000000 as a minimum and maximum population respectively.

The PF evaluated from the previous equations is varied from one method to another. The PF is one of the main factors that affect the design of sewer networks, pump stations and wastewater treatment plants. In some cases it may not be realistic to the actual flow, which may raise the cost of construction and operation of sewerage projects.

Therefore, developing realistic equations is important to achieve optimum design for sewer networks and pump station. The main goal of this research is to improve the real peaking factor equations depending on the population and average consumption to minimize the capital cost and operational cost of sewerage projects. The study was performed in two different areas in Upper Egypt. The developed peaking factors equations are compared with the previous studies. The peaking factors are integrated into maximum flowrate equations that can be used for the hydraulic design of new sewer lines and pumping stations.

II. METHODOLOGY

Sewage flows from two different areas in Upper Egypt were evaluated to determine maximum flowrate and peaking factors for each studied area. The criteria for the selection of these cities were based upon: population variation, and availability of data for the study. The areas selected were two regions in Asyut (Meir station, Al-Qusiya station).

Approximately ten years of flow data were evaluated including the values of minimum, average and maximum flows for each area. The data of the two areas were analyzed to determine peaking factor equations depending on the population numbers and average consumption of capita per day. Afterwards, the obtained results were compared to the results of the empirical equations.

The population data were collected from Central Agency for Public Mobilization and Statistics. A portable ultrasonic flow meter was mounted on the discharge pipe of the pumping station to measure the sewage flows. The P.F equations were developed using the SPSS (Statistical Package for Social Sciences) and compared to values computed according to the equation of the Egyptian code.

Al-Qusiya (formerly called Qais) is a city and center in Asyut Governorate. It is a city struck in ancient history, and was the northern border of the ancient Egyptian state. The city of Qusiya is located in the north of Asyut governorate and is bordered to the north by the center of Dairout, and to the south by the center of Manfalut. The city of Qusiya is located directly on the Abrahamic canal.

Meir is a village in Upper Egypt. It is located on the west bank of the Nile, in the Asyut Governorate, some 7 kilometers southwest away from Al-Qusiya.

The pump stations data for the two areas of study including the number of working and standby pumps, the monomeric head of the pumps, the discharge and the operation working hours of each pump per day are shown in table (1).

The population and actual flow according to collected data for the studied pump stations are shown in table (2).

TABLE 1
THE PUMP STATIONS DATA

Station	Working Pumps	Standby Pumps	Pump Discharge (l/sec)	Head of Pump (m)	minimum Operating Hours	Average Operating Hours	maximum Operating Hours
Al Qusiyya	1	2	400	70	14	16.5	19
Meir	1	2	90	60	14	16	18

TABLE 2
POPULATIONS AND ACTUAL MAXIMUM FLOW RATE FOR STATIONS

Year	Al Qusiyyah		Meir	
	P_{Capita}	$Q_{max.actual}$ (m^3 /d)	P_{Capita}	$Q_{max.actual}$ (m^3 /d)
2008	89259	20160	-------	-------
2010	94648	21600	28912	4536
2012	108891	23040	30855	4860
2014	123246	24480	32841	5184
2016	129935	25920	34832	5670
2018	135593	27360	35842	5832

The obtained data was also used to calculate the peak factor according to Egyptian code. Statistical analysis was used to develop new equations to evaluate the peak factor of the studied zones for Upper Egypt region.

III. RESULTS AND DISCUSSION

The flow data for each area comprised of 365 days of measured hourly flows and about eight years of measured total daily flows was analyzed in this study.

The measured peak factor (P.F) and the developed values from year 2010 to 2018 are shown in figures 1 and 2. The collected data was used to calculate the actual peaking factor according to Egyptian code to develop P.F equations for populations for Meir and Al-Qusiya pump stations as shown below.

$$PF_5\ (P) = 2 \times \frac{5.5}{P^{0.458}} \qquad (7)$$

Where P is estimated in thousands and ranged from 15,000 to 80,000 and a factor of safety equals (2) has been used in equation (7).The developed equation is well fit the actual data with correlation factor equal to 87 % depending on the measured data for Meir pump station as shown in Fig (1).

The collected data for Al-Qusiya lift station used to develop real equation as shown below:

$$PF_6\ (P) = 1.05 \times \left(\frac{240+P^{1.46}}{5+P^{1.46}}\right) \qquad (8)$$

Where P is estimated in thousands and ranged from 80,000 to 1,000,000. and a factor of safety equals (1.05) has been used in equation (8). The developed equation is well fit the actual data with correlation factor equal to 91 % depending on the measured data for Al-Qusiya station as shown in Fig (2).

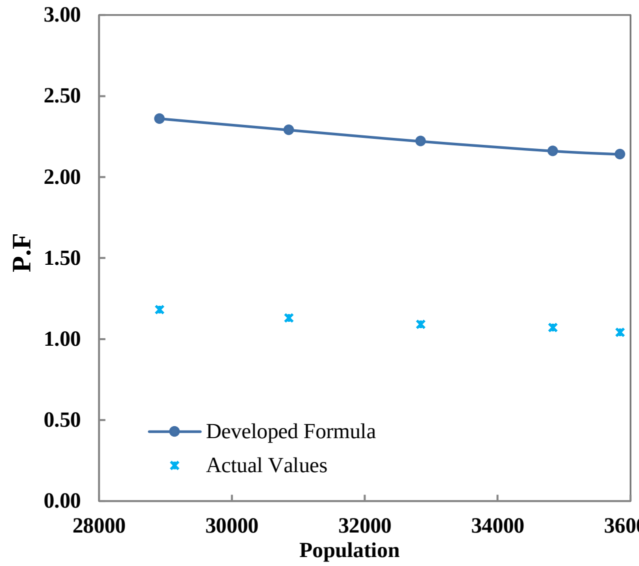
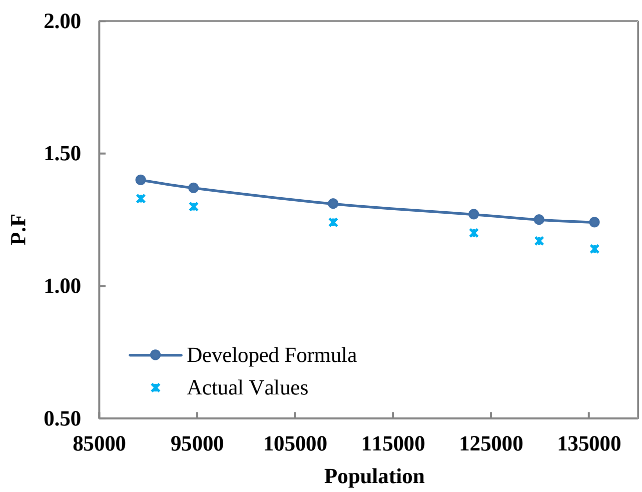


Fig. 1 P.F estimation from developed formula, and actual values for Meir station



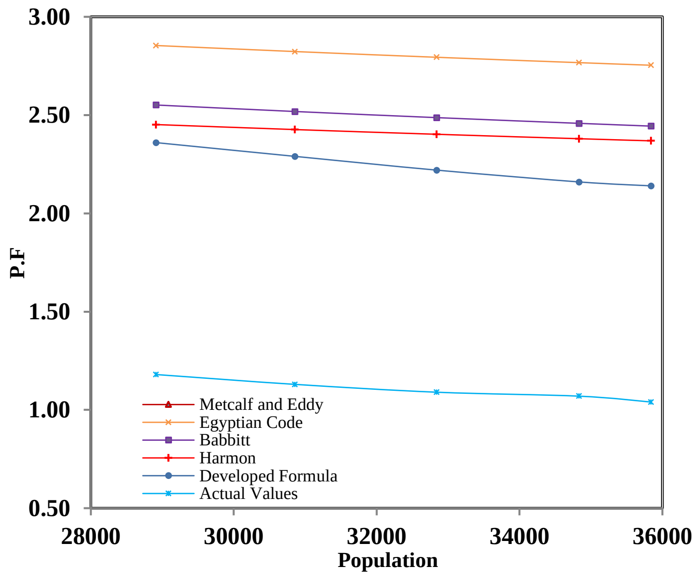
(Fig. 2) P.F estimation from developed formula, and actual values for Al-Qusiya station

All results have the same trend. The peak factor (PF) declines with increasing population. The developed P.F decreased by 20 % and 33 % on average for stations Meir and Al-Qusiya, respectively compared to the P.F obtained by recommended empirical equations according to the Egyptian code as shown in table (3).

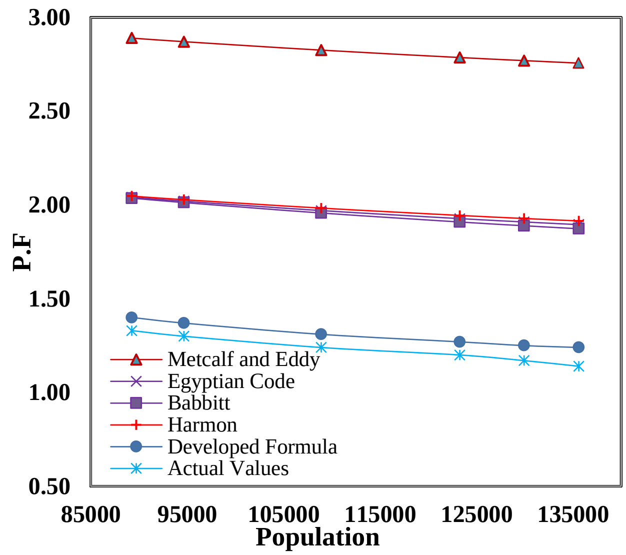
TABLE 3
PERCENTAGE OF DECREASED P.F

Station	Meir Station		Al-Qusiya	
	Code	Developed	Code	Developed
2008	-----	-----	2.04	1.40
2010	2.85	2.36	2.02	1.37
2012	2.82	2.29	1.97	1.31
2014	2.79	2.22	1.93	1.27
2016	2.77	2.16	1.91	1.25
2018	2.75	2.14	1.89	1.24

The relations between the measured peak factor (P.F) and population (P) through the period from 2008 to 2018 for lift pumping stations Meir and Al-Qusiya respectively compared with the developed P.F equation and with the previous studies are illustrated in figures 3, and 4.



(Fig. 3) P.F estimation from empirical methods, and developed formula for Meir station



(Fig. 4) P.F estimation from empirical methods, and developed formula for Al-Qusiya station

All results have the same trend, that the peak factor (PF) declines with increasing population. It is quite interesting to notice that the PFs estimated using the empirical equations resulting from previous studies lie above the PF estimated using the developed formula and above the measured P.F. The derived values of peak factor for all communities in this study are smaller than the values calculated from previous studies.

The collected data for Meir pump station used to develop another new equation for estimating wastewater peaking factors are shown below:

$$PF_7\ (P) = 2 \times \frac{0.5}{Q^{0.235}} \qquad (9)$$

Where q ranged from 125 to 140 l/C/d and P ranged from 15,000 to 80,000 capita and a factor of safety equals (2) has been used in equation (9). The developed equation is well fit the actual data with correlation factor equals 81 % depending on the measured data for Meir pump station as shown below in fig(5).

The collected data for Al-Qusiya station used also to develop new equation function of flowrate for estimating wastewater peaking factors are shown below:

$$PF_8 = 1.2 \times \frac{1.1}{Q^{0.136}} \qquad (10)$$

Where q ranged from 145 to 200 l/C/d and P ranged from 80,000 to 1,000,000 capita and a factor of safety equals (1.2) has been used in equation (10). The developed equation is well fit the actual data with correlation factor equals 85 % depending on the measured data for Al-Qusiya station as shown below in fig (6).

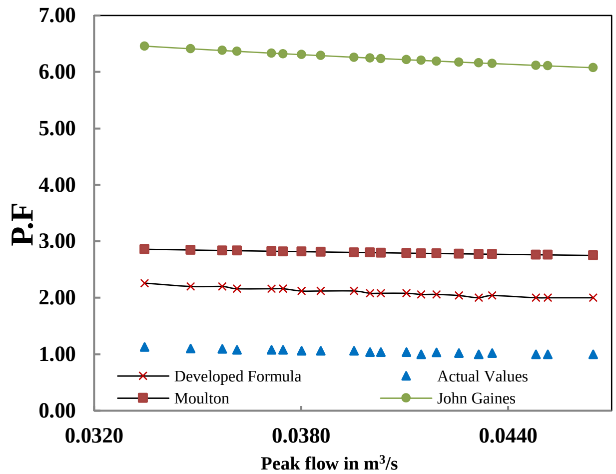


Figure (5) Relation between the peak factor (P.F) and flowrates (Q) for Meir station along period from 2010 to 2018.

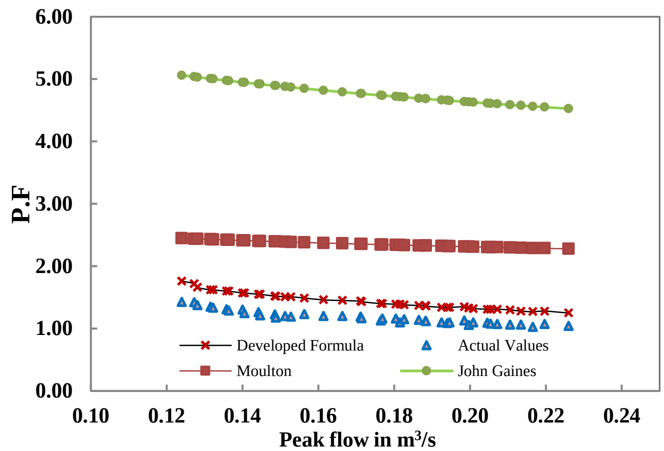


Figure (6) Relation between the peak factor (P.F) and flowrates (Q) for Al-Qusiya station along period from 2008 to 2018.

All results have the same trend, that the peak factor (PF) declines with increasing population. It is quite interesting that the PFs estimated using the empirical equations from previous studies lie above the PF estimated using the developed formula and above the actual P.F. The derived values of peak factor for all communities in this study are smaller than the values calculated from the equations from Moulton and Gaines. This may be due to the arid communities' characteristics in this study and the different characteristics of the communities for previous study. This may return back to, the variation in characteristics of the communities investigated by Gaines, J. B. (1989) and Moulton, R. B. (1999).This means that conventional practice for estimating wastewater peaking factors is quite conservative, giving values with a relatively low risk of exceedance.

IV. Conclusions

This study of Upper Egypt areas has been investigated to derive probability based design maximum flow factors for the design of the sewerage system.

Each wastewater component of the sewerage system should be designed with its own flow factor based on its acceptable limits of behavior by using the "beginning of service" population /average flowrates along with the peaking equation then the "design maximum flowrates" calculated actually. By using the "design life" population/average flowrates and peaking equation, the design maximum flowrates are established (for capacity design).

In this study equation (7) suggested for estimating wastewater peaking factors for populations from 15000 to 80000 and equation (8) suggested for estimating wastewater peaking factors for populations from 80,000 to 1000,0000.

Equation (9) suggested for estimating wastewater peaking factors as function of flow rates for q ranged from 125 to 140 l/C/d and Equation (10) suggested for estimating wastewater peaking factors as function of flow rates for q ranged from 145 to 200 l/C/d .

Generally, peak factors decline with rising average flow rates. Peak factor values are higher for smaller areas than larger areas because small flow rates are sensitive to changes. For example, a slight change in water use causes a relatively large rise or decline in total wastewater flow for the area served. On contrast, slight change in water use in larger areas would result in relatively small raises or reduces in total flow for the served area.

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