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Effect of Sustainable Water Management on the Hydraulic Performance of Sewer Pipes Network

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Abstract: The gab between fresh water supply and demand in Egypt is rapidly increasing due to population growth and limited water resources. So, management of water resources became one of omnipresent problems that spared national and regional scale. To meet the water needs of the present as well as future generations, our water resources must be managed in a sustainable manner. This could be achieved in the three sectors of water consumption, i.e. agricultural, domestic and industrial. The sustainable management of water resources can be implemented through two tracks (conservation and reuse) in every sector of water consumption. In domestic sector, many measures can be applied beginning with reducing the water losses in water supply pipes network and ending with home level by periodical maintenance of the plumping system and installing conservation measures on the different equipment at home. The other track can be focus on the separation of the grey water (low pollution) from black water (high pollution) at on site level and reuse of grey water for non-potable uses such as toilet flushing and garden irrigation. This method will be very effective in the new communities. Due to applying conservation and reuse measures, quantity of wastewater flow to the sewer pipes network will be reduced and the concentration of pollutants will be increased which will affect the hydraulic performance of the sewer pipes network.In this research, effect of reduction in the quantity of wastewater flow on the behavior of sewer pipes network is investigated. A hypothetical sanitary sewer pipes network is studied using extended period simulation method. Three scenarios for the wastewater flow are studied. It was found that the influence of flow reduction will be dominant at the beginning part of the network and all the hydraulic parameters are affected by flow reduction.

Key words: SewerCAD · Greywater · Water conservation · Sediment transport

INTRODUCTION

Water is the most precious resource and Egypt is one of the driest countries facing enormous shortage of potable water. Nowadays, people are increasing and becoming aware of the need to preserve water and sustainable water management through greywater reuse may be one of the best options to preserve potable water. Greywater reuse has been implemented in many countries but it is relatively new in our region. Greywater reuse will result in reduction of amount of wastewater flowing in sewer pipes network which will affect on its hydraulics performance. Many researchers studied the flow in sewer pipes network from different view of points, among of them Banasiak [1], Abdulqader *et al*. [2], Hosseini and Ghasemi [3], Katti *et al*. [4] and Rai and Deshmukh [5]. Penn *et al*. [6] studied the expected effects of change in urban wastewater quantity as a result of greywater reuse on gross solid movement in sewer. It was shown that the movement of gross solids in the upstream links differs than that of the downstream links and throughout the day. Babani *et al*. [7] used the computer program SWMM to simulate hydraulic bottlenecks, surcharged pipes and overflowing manholes on representative parts of a network for a period of 50 years considering the current and anticipated hydraulic conditions. Godfrey *et al*. [8] presented results from 6 greywater reuse systems which were built with the objective to augment water supply and to provide sanitation in rural low income areas in India. The systems are based on reclaiming greywater from bathing for the use in toilet flushing and kitchen garden irrigation. They concluded that greywater is a highly cost

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effective solution for water scarcity and reusing greywater resulted in a 60% increase in water availability, a reduction in open defecation and a fourfold increase in food availability. Marleni *et al*. [9] investigated the wastewater parameters which cause the problems of odour and corrosion in sewerage networks due to source management practices. These parameters are: chemical oxygen dmand (COD), nitrate (NO_3), Sulphate (SO_4), iron (Fe), copper (Cu), Zinc (Zn) and total suspended solid (TSS). Oms *et al*. [10] performed velocity measurements using a micropropeller and an Acoustic Doppler Velocimeter (ADV) in two sewer trunk line to identify practical technique for estimating bed shear stress in combined sewers. They concluded that in sewers without sediments, both the wall law and Reynolds shear stress distribution method lead to the same bed shear stress estimation. Guzman *et al*. [11] studied the effect of biological film development on the internal sewer pipe surface utilizing a pilot-scale sanitary sewer. They claimed that the shear stress to move particles of a given size is independent of slope and pipe diameter, but does depend on the effect of biological film on increasing the roughness coefficient. They found that the critical shear stress to achieve self-cleaning in sanitary sewer in the range of 1.1- 1.4 N/m^2, depending on the integrity of the biofilm.

The objectives of this paper are: to explore the behavior of sewer pipes network in extended period flow for 24-hours, study the effect of reduction of wastewater flow due to applying conservation measures and reusing of greywater on the flow characteristics in sewer pipes network and to study its efficiency in sediment and other suspensions transport.

The paper is organized as follows. It starts with introduction along with the presentation of importance and the previous studies for the subject. The second section is devoted to the detailed description of methodology and application of the study. In the result section, the concept is applied on different scenarios to predict water level and bed shear stress in sewer pipes. In the final section some concluding remarks and recommendation are drawn.

Methodology: Hydraulic models are important tools for the analysis and design of sewer pipes network. Engineers use these models for various important tasks, such as the design of new one and the analysis of existing sewer pipes network, long-term master and operational planning. Numerous computer models have been developed to solve the network simulation equations. Among of the more widely used models are Sewer Cad and SWMM5, which can simulate steady state conditions and extended period simulation. In the current study, SewerCAD V8i was used in extended period simulation for the flow in the sewer pipes network.It continues to be widely used throughout the world for planning, analysis and design related to sanitary sewers and other drainage systems in urban areas. The hydraulic capabilities of SewerCAD include modeling any size sewer pipes network.

The numerical methods have been developed to simulate the unsteady flows in sewer systems are divided to two types, including those based on explicit numerical schemes and those based on implicit schemes, limitations in most of models exist. SewerCAD V8i features engines capable of solving the dynamic solution using both schemes. Users may select to either user EPA SWMM's native explicit solver or a custom implicit solver as more fully described in this section. The implicit solver is the default solver used in SewerCAD V8i. The Saint-Venant equations of one-dimensional unsteady flow in non-prismatic channels or conduits are the basic equations for unsteady sewer flows. The dynamic model solution uses the following complete and extended equations:

$$\frac{\partial Q}{\partial x} + \frac{\partial (A+A_o)}{\partial t} - q = 0.0 \quad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (\beta Q^2/A)}{\partial x} + gA\left(\frac{\partial y}{\partial x} - S_o + S_f + S_e\right) + L = 0.0 \quad (2)$$

where

t = time

x = The distance along the longitudinal axis of the sewer reach

y = Flow-depth

A = The active cross-sectional area of flow

A0 = The inactive (off-channel storage) cross-sectional area of flow

q = Lateral inflow or outflow

β = The coefficient for nonuniform velocity distribution within the cross section

g = Gravity constant

So = Sewer or channel slope

Sf = Friction slope due to boundary turbulent shear stress and determined by Manning's equation

Se = Slope due to local severe expansion-contraction effects (large eddy loss)

L = The momentum effect of lateral flow

Fig. 1: Sewer pipes network.

Table 1: Lengths, diameters and slopes of the different pipes.

Pipe number	Length (m)	Diameter (mm)	Slope (m/m)	Pipe number	Length (m)	Diameter (mm)	Slope (m/m)
CO-1	51	200	0.002	CO-16	50	200	0.008
CO-2	52	200	0.005	CO-17	44	250	0.008
CO-3	44	250	0.004	CO-18	45	250	0.008
CO-4	48	250	0.004	CO-19	71	250	0.004
CO-5	51	250	0.008	CO-20	47	250	0.008
CO-6	59	250	0.008	CO-21	46	250	0.008
CO-7	46	250	0.008	CO-22	46	250	0.008
CO-8	32	250	0.003	CO-23	45	250	0.008
CO-9	53	250	0.004	CO-24	52	200	0.006
CO-10	60	400	0.003	CO-25	48	200	0.005
CO-11	44	200	0.003	CO-26	54	300	0.005
CO-12	33	200	0.008	CO-27	76	300	0.005
CO-13	59	200	0.005	CO-28	50	200	0.008
CO-14	50	200	0.005	CO-29	50	200	0.004
CO-15	54	200	0.005	CO-30	50	200	0.004

Application: This research is based on hypothetical sewer pipes network shown in Fig. (1). The ID labels for the various components are shown in the figure. The average wastewater inflow to the network is taken as a constant value at all manholes junction of 0.63 litre/s, which act as the start of the sewer connection. This discharge is considered the dry weather discharge from houses. The network is composed of 30 pipelines with different lengths, diameters and slopes, as shown in Table 1. It was assumed that PVC pipes would be used throughout the system with the same values of Manning's roughness coefficient of 0.013, the flow depths, velocities, bed shear stress and other flow characteristics are computed by applying the continuity and energy equations at all nodes

Table 2: Daily time variation of wastewater flow.

Time Interval	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0
Flow multiplier	0.65	0.34	0.22	0.20	0.21	0.25	0.60	1.26	1.61	1.68	1.64	1.50
Time Interval	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0
Flow multiplier	1.34	1.18	1.09	0.99	1.00	1.08	1.23	1.33	1.31	1.21	1.12	0.94

(manholes) of the sewer pipes network.The conduit type was circular without sediment accumulation on the bedand the values of average waste water inflow were changed three times to take the normal case (0.63 l/s), 0.8 times the normal case and 0.6 times the normal. This reduction in wastewater inflow represents applying water conservation measures and onsite reusing part of grey water. The model was run for 24 hours.

Daily Curve of Wastewater Flow: A daily curve that makes wastewater flow at the manholes of the used network vary in a periodic way over the course of the day was used to make the sewer network more realistic for analyzing an extended period of operation. The following table (Table 2) illustrated the typical time variation of wastewater flow.There is relatively little sanitary flow at night, increased flow during the early morning hours as people wake up and prepare for the day, decreased flow during the middle of the day and finally, increased flow again in the early evening as people return home.

Sediment Transport in Sewer Pipes: Good design of sewer pipe must fulfill "self-cleaning" velocities during normal daily peak flow periods to transport grit which may enter the sewer. For self-cleaning evaluation, the general accepted standards often require a minimum critical velocity or a minimum critical shear stress.

According to many references (Dlas and Matos [12], Bong [13]), the velocity required to transport sediments in pipes may be given by the following expression:

$$v_c = \frac{1}{n} R^{\frac{1}{6}} \sqrt{\beta(S.G.-1)d_s} \tag{3}$$

where v_c= self-cleaning velocity (m/s); R= hydraulic radius (m); n= Manning's roughness coefficient ($m^{1/6}$/s); S.G.= specific gravity of the particles (-); d_s= equivalent diameter of the particle (m); β= dimensionless constant.

The value of the constant "β" is about 0.04 to start motion of clean granular particles and of about 0.8 for cohesive material.

The average boundary shear stress on the wetted perimeter of the sewer can be expressed as follows:

$$\tau = \gamma R S \tag{4}$$

where τ= average boundary shear stress (N/m^2); γ= specific weight of the water (N/m^3); S= sewer invert slope (-).

The critical shear stress required to transport sediments in pipes can be given by the following expression:

$$\tau_c = \gamma\beta(S.G.-1)d_s \tag{5}$$

The symbols in Eqn. (5) are as mentioned above.

The general accepted standard of a minimum critical velocity of 0.6 m/s, for the daily peak flow conditions in many codes and standards, corresponds to a shear stress between 1.5 and 2.0 N/m^2.

RESULTS AND DISCUSSIONS

Fig. (2) shows a longitudinal profile and water surface profile for the sewer pipeline beginning with segment CO-19 to the end of the pipeline, i.e. segment CO-10 at time 10 AM, which considered the peak flow hour, for scenario of normal flow case. As shown from this figure, the flow is free surface for whole the pipeline and the flow depth is less than the half of the diameter except the last three segments because they receive the flow coming from whole of the network.

Figs. (3) and (4) illustrate the mean velocity variation in pipe segment CO-2 (most upstream) and CO-23 (most downstream) through 24 hours for the three cases of flow. For pipe CO-2, it can be shown that velocity less than 0.5 m/s for all the day. For pipe CO-23, it is shown that the minimum values are 0.37, 0.35and 0.32 m/s at hours 3 and 4 AM for normal flow case, 80% of normal flow and 60% of the normal flow respectively. The maximum velocities are 0.69, 0.65 and 0.6 m/s at hours 9 and 10 AM for the three cases of flow from higher to lower flow respectively. Of course, these values may be decrease for the upper reaches of the pipe network and at reaches of milder slopes. The peak flow velocity is higher than the minimum self-cleaning velocity which taken as 0.6 m/s by many references, so it is expected that the grit deposited during minimum flow period to be flushed at the peak flow period for the three cases of flow.

Fig. 2: Longitudinal profile in the sewer pipeline from segment CO-19 to segment CO-10 at time 10 AM.

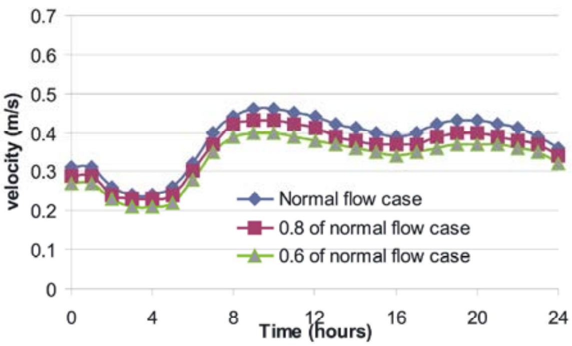

Fig. 3: Time variation of mean velocity in pipe CO-2 for normal flow, 0.8 of normal flow and 0.6 of normal flow cases.

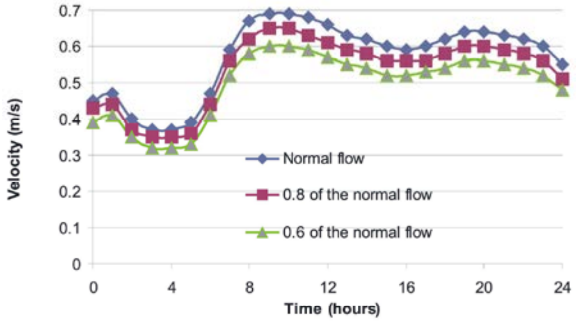

Fig. 4: Time variation of mean velocity in pipe CO-23 for normal flow, 0.8 of normal flow and 0.6 of normal flow cases.

Figs. (5)and (6) present the time variation pattern of the bed shear stress for pipessegmentCo-2 and CO-23 of the sewer network for the three simulated scenarios of flow in sewer pipes network.It can be shown from Fig. (5) that the maximum shear stress is slightly higher than 1.0 for peak flow hour for case of normal flow and decrease to less than 1.0 due to reduction in wastewater flow quantity. As shown from Fig. (6), the minimum shear stress occurs at 4:00 AM with a value less than 1.0 N/m^2 for the three cases of flow. However, the maximum value of shear stress occurs at 9:00 AM with a value equals to 2.484, 2.249 and 2.036 N/m^2, respectively. In comparison between the maximum values of shear stress in the pipe and the critical value estimated using Eqn. (3), it is clear that the bed shear stress at peak hour is greater than the critical bed shear stress for grit and sediment movement for the three scenarios of flow. So, the simulation revealed that there is no accumulation for the sediment in the pipe.

Fig. (7) shows the time variation of Froude number for pipe CO-2 at the three cases of flow. It is clear from that figure, Froude number is less than one for all the time period. So the flow is subcritical. However, in Fig. (8), the variation of Froude number with the time is shown for pipe segment CO-23. It can be noticed from that figure, the flow is supercritical all the day for the first two scenarios with a value of Froude number greater than one. In the third scenario, Froude number less than one in the period from 2:00 to 5:00 AM and the flow is super critical for the rest of the day.

Table (3) shows the values of mean velocity, mid water depth and bed shear stress at peak flow hour for the three scenarios of flow. From that table, it can be seen that the upstream segments of sewer network does not satisfy the limits of self-cleaning velocity and minimum bed shear stress for sediment movement. In general, the three parameters decrease by decreasing the amount of wastewater flow. For all pipes having a velocity and bed shear stress upper than the minimum value, three pipes changed their case to lower than the minimum value by reducing the discharge.

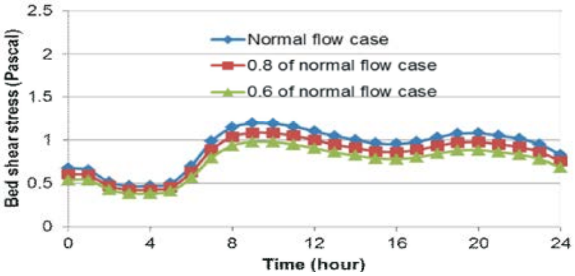

Fig. 5: Time variation of bed shear stress in pipe CO-2 for normal flow, 0.8 of normal flow and 0.6 of normal flow cases.

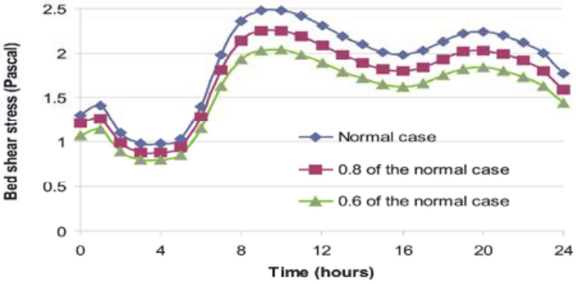

Fig. 6: Time variation of bed shear stress in pipe CO-23 for normal flow, 0.8 of normal flow and 0.6 of normal flow cases.

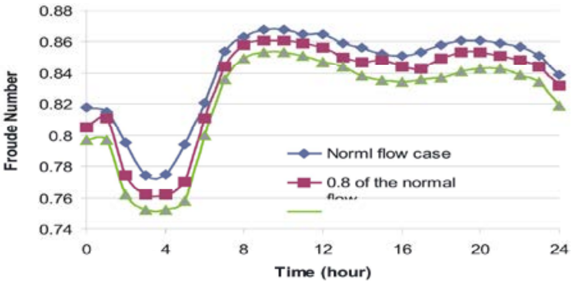

Fig. 7: Time variation of Froude number in pipe CO-2 for normal flow, 0.8 of normal flow and 0.6 of normal flow cases.

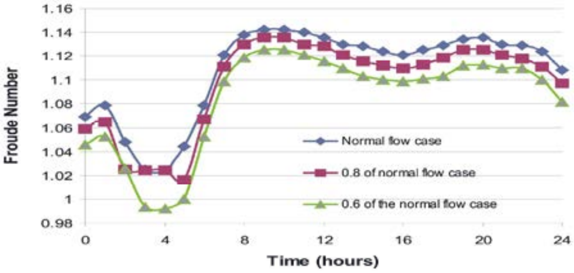

Fig. 8: Time variation of Froude number in pipe CO-23 for normal flow, 0.8 of normal flow and 0.6 of normal flow cases.

Table 3: Velocity, Water depth at the mid pipe and bed shear stress in the pipesat peak flow hour.

	Normal flow case			0.8 of normal flow case			0.6 of normal flow case		
Pipe number	v (m/s)	y (mm)	τ (Pascal)	v (m/s)	y (mm)	τ (Pascal)	v (m/s)	y (mm)	τ (Pascal)
CO-1	0.27	40	0.428	0.25	35	0.387	0.24	30	0.35
CO-2	0.46	45	1.197	0.43	40	1.085	0.4	35	0.981
CO-3	0.47	55	1.176	0.44	45	1.065	0.41	40	0.963
CO-4	0.51	70	1.353	0.48	60	1.228	0.45	50	1.111
CO-5	0.84	85	3.356	0.79	75	3.051	0.74	65	2.77
CO-6	0.86	95	3.496	0.81	85	3.177	0.76	75	2.886
CO-7	0.95	120	3.995	0.89	110	3.642	0.83	95	3.312
CO-8	0.75	145	2.289	0.71	130	2.113	0.67	110	1.937
CO-9	0.77	150	2.409	0.73	130	2.225	0.69	115	2.041
CO-10	0.73	135	2.008	0.68	120	1.882	0.64	110	1.665
CO-11	0.31	35	0.588	0.29	30	0.532	0.27	30	0.481
CO-12	0.54	50	1.709	0.48	40	1.422	0.45	40	1.286
CO-13	0.6	70	1.799	0.56	65	1.636	0.53	55	1.485
CO-14	0.37	35	0.886	0.35	35	0.8	0.33	25	0.727
CO-15	0.46	50	1.199	0.43	50	1.087	0.4	40	0.982
CO-16	0.44	35	1.274	0.41	25	1.153	0.39	25	1.041
CO-17	0.53	40	1.652	0.49	35	1.492	0.46	30	1.35
CO-18	0.59	70	1.986	0.56	65	1.797	0.52	55	1.623
CO-19	0.33	35	0.705	0.31	30	0.637	0.29	25	0.574
CO-20	0.53	40	1.668	0.49	35	1.506	0.46	30	1.362
CO-21	0.59	45	1.991	0.56	45	1.802	0.52	35	1.627
CO-22	0.65	55	2.259	0.61	50	2.047	0.57	45	1.853
CO-23	0.69	100	1.142	0.65	90	2.249	0.6	80	2.036
CO-24	0.39	35	0.962	0.36	35	0.871	0.34	25	0.788
CO-25	0.46	40	1.199	0.43	40	1.087	0.4	35	0.982
CO-26	0.49	45	1.33	0.46	45	1.203	0.43	40	1.087
CO-27	0.54	100	1.51	0.5	90	1.368	0.47	80	1.237
CO-28	0.44	35	1.274	0.41	30	1.153	0.39	30	1.041
CO-29	0.4	45	0.908	0.38	45	0.823	0.35	40	0.745
CO-30	0.45	100	1.08	0.42	90	0.981	0.4	80	0.888

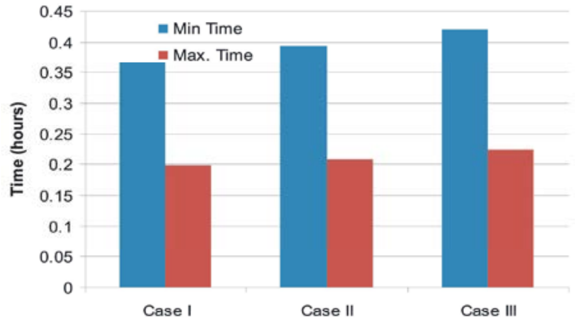

Fig. 9: Travel time through sub-branch CO-19: CO-10.

Time of Travel in Sewer Pipes Network: The travel time of wastewater is very important where it controls the dissolving of organic components in wastewater which causes odour problems. Time of travel in sewer pipes network is found by summing the time for each individual flow segment within the drainage area.

$$T_t = \sum_{i=1}^{n} T_i \qquad (6)$$

whereT_t= total travel time ; T_i= flow travel time through segment I.

$$T_i = \frac{L_i}{v_i} \qquad (7)$$

where L_i is the segment length and v_i is the mean velocity in the segment.

Fig. (9) shows the maximum and minimum travel time through sub-branch CO-19 to CO-10 for the three cases of flow normal flow, 0.8 of the normal flow and 0.6 of the normal flow. It can be noticed from that figure increasing of travel time by decreasing the wastewater flow capacity.

CONCLUSIONS

It is both difficult and costly for utilities to update and maintain accurate data bases for extended time period. Available extended time period models capable of long-term analysis are highly desirable. In this study, SewerCAD software is used for flow simulation in sewer pipes network. Three scenarios for the wastewater flow in sewer pipes network are studied, i.e. normal flow case, 80% of the normal flow case and 60% of the normal flow case.It was found that the water depth, velocity and bed shear stress values decrease by reducing the wastewater flow rate which affect on grit and sediment deposition in the pipe. The critical pipes for sediment deposition are the upstream pipes. The travel time increases by decreasing the wastewater flow capacity.

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