Journal of Engineering Science and Technology
Vol. 13, No. 12 (2018) 4094 - 4103

OPTIMUM OPERATION MANAGEMENT EFFECT OF MAIN SEWAGE PUMPING STATIONS ON TRUNK SEWER DETERIORATION

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Abstract

Sewage pumping stations are considered an important part of any sewerage system. Pumps failure in these stations means that the pumps are unable to work at the design requirement (flow capacity and head) and that may cause sewer overflow and flooding leading to sewer deterioration. In this paper, two main sewage pumping stations in Baghdad city were selected as case studies, Al-Habibia and Al-Ghazali located on Zublin trunk sewer 3000 mm and Baghdad trunk sewer 1200-2100 respectively. This study focused mainly on the operation of main sewage pumping stations and their effect, both directly and indirectly, on changing hydraulic properties, which leads to an increase in the deterioration of sewage pipes. The hydraulic analysis was conducted to investigate the effect of the operational performance of these stations on the deterioration of the trunk sewers. In general, the sewage pumps are in good condition based on the completed evaluation of these stations but, it was observed that Al-Habibia sewage pumping station was unable to discharge high sewage flow (d/D = 0.75). Backup flow occurred in the inlet sewer and caused overflow and flooding. The hydraulic analysis for the effluent sewer showed that the actual flowing velocities of the operating conditions examined were greater than the minimum self-cleaning velocity. Al-Ghazali sewage pumping station was able to receive the influent sewage for all the cases of flow (low, medium and high). While the effluent sewer (Baghdad trunk sewer) that was 70% filled with sediments, that reduced its capacity, does not work with the high discharges of the pumps. Therefore, resulting in sewage flows from this overloaded sewer onto the streets and harms the environment.

Keywords: Hydraulic analysis, Operational performance evaluation, Pumps condition, Sewage pumping stations, Trunk sewer deterioration.

1. Introduction

The sewerage system construction in a flat area is required a large number of pumping stations due to the depth of the affected groundwater, which indicates the occurrence probability of technical problems as increasing the cost of pumping operation and reduce system life cycle [1]. For many cities in Iraq with a flat area, the pumping station is considered an integral part of the sewerage system. Pumping station uses pumps (mechanical equipment) and forces main (pressurized piping) to lift sewage from a low to a higher elevation point and transport it to the gravity portions of this system [2].

As commented by Chiang et al. [3], the applicability and reliability in automatically operating of the sewage pumping stations through controlling the wastewater level within design requirement to maintain the safety of urban sewage systems to make the existing sewerage systems more effective or propose a new system of pumping and discharging wastewaters. Pumps failure may cause sewers overflow and flooding in an urban drainage system leading to sewers deterioration. According to Ursino and Salandin [4], however, the failure of the system may be due to the failure of one or more pumps that are unable of pumping the design capacity or an unexpected rainfall event that exceeds this design capacity. In addition, the stations located within residential areas are associated with large sewage flow corresponding to large residential developments [5]. The increase in sewage amounts, from additional developments, has dictated the need for correcting the hydraulic analysis of the sewer system, which was performed for design requirements of the sewage pumping stations. Based on studies by Jones et al. [6], if the pumping station stops working, a backup flow can occur in the inlet sewer and leading to overflow (i.e., the raw sewage is being discharged into the environment). The objective of this paper is to evaluate the operational performance of sewage pumping stations and investigate their effect on trunk sewers deterioration. Also, to identify the problems that occur at these stations that affect their performance. Two main pumping stations are selected as case of studying, Al-Habibia on Zublin trunk sewer and Al-Ghazali on Baghdad trunk sewer.

In order to judge the sewage pumping stations, operate at an acceptable level, the following criteria are recommended:

- The actual flowing discharge that is received by the pumping station (inflow) must be less than the station overall design capacity.
- The pumps themselves should be in good condition, which can be assessed according to visual inspection from site investigation, their age, maintenance program and inflow-outflow quantity.
- The velocity in the inlet and outlet gravity sewers must be greater than the minimum allowable velocity 0.6 m/s [7] as this velocity is enough for scouring the sediments in these sewers, which helps in keeping the system clean for actual design flow conditions.

2. Material and Methods

2.1. Case studies description

Site visits were conducted to obtain a better overview of the condition and size of problems in the selected stations as case studies. Various municipalities were also visited to gain as much knowledge of these stations and the possible problems that occur.

2.1.1. Al-Habibia sewage pumping station (SPS)

This SPS was established on Zublin trunk sewer in Al-Rusafa side of Baghdad city in 1981 as shown in Fig. 1. This station receives 7.652 m^3/s sewage flow by gravity from three regions Al-Shaab, Al-Sadr1 and Al-Sadr2. The overall design capacity of this station is 11 m^3/s, so it is capable of handling the inflow discharge. A 3 m sewer enters the SPS into two stages each stage has two sewers of 2 m diameter with a manually cleaned bar screen to remove large solids. Sewage exiting the bar screens flows into two wet wells each of (3.5×5×7) m in volume. Adjacent to the wet wells are two dry pits, each one contains five pumps. A collection chamber of volume (4×48×5.15) m receives sewage from the pumps and discharge it into a 3000 mm gravity sewer, which runs for approximately 13 km reaching Al-Rustamiya Sewage Treatment Plant (STP). A total of ten pumps are in Al-Habibia SPS, four of the capacity of 1.5 m^3/s, four of 1 m^3/s and two of 0.5 m^3/s [8].

2.1.2. Al-Ghazali sewage pumping station (SPS)

This station was established on Baghdad trunk sewer in Al-Rusafa side of Baghdad city and operated in 1970 as shown in Fig. 1. The sewage enters the station by a 1.6 m sewer, flowing by gravity from two regions Al-Adhamiya and Al-Rusafa with discharge 3.301 m^3/s, which is less than the station overall design capacity (6 m^3/s). Sewage exiting the bar screen flows into two wet wells each one of volume (6×4×12) m. Adjacent to the wet wells is the dry pit, which contains five pumps discharging into a 1.85 m sewer, which runs for approximately 13 km to the old Al-Rustamiya STP. Al-Ghazali SPS contains five pumps, two of discharge 1.5 m^3/s and three of 1 m^3/s [9].

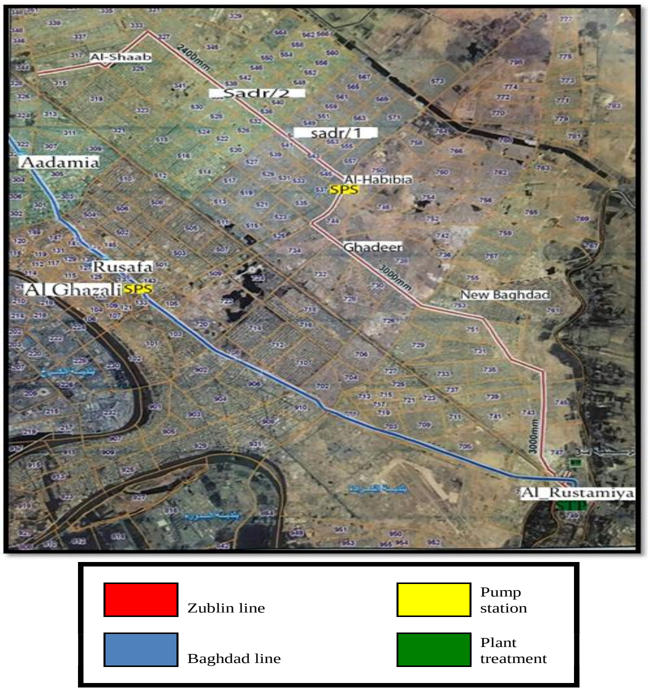

Fig. 1. Locations of Al-Habibia and Al-Ghazali sewage pumping stations [8, 9].

2.1.3. Hydraulic analysis

The trunk sewer has able to transport sewage and/or stormwater to the STP efficiently (i.e., avoiding the occurrence of regular flooding in stormwater gullies and streets). As explained by Ana [10], tor the hydraulic design, the trunk sewer diameter should be able to transport the flow composed of Dry Weather Flow (DWF) (i.e., sanitary sewage only in dry seasons) and/or stormwater, wet weather flow (WWF) depending on the type of the trunk sewer (i.e., combined or separate system).

Zublin and Baghdad trunk sewers are combined types designed to carry both DWF and WWF. The hydraulic analysis of these sewers is according to the following steps (based on DWF):

Step 1: Determine the actual flow discharge (q_p) from the sewage pumping station. Three cases are considered in this study for the pumps operating conditions; in the morning, at peak time and at night.

Step 2: Determine the full flow condition discharge Q and velocity V from Manning's formula using Eqs. (1) and (2) [7]:

$$Q = \frac{1}{n} R^{2/3} S^{1/2} A \quad (1)$$

$$V = \frac{1}{n} R^{2/3} S^{1/2} \quad (2)$$

With *n* being roughness coefficient, which depends on pipe material (0.013 for concrete), *R* is a hydraulic radius that is equal to (*D/4*) for full flow condition (*D* is the diameter of the sewer), *S* is sewer longitudinal slope and A wetted area for full flow ($\pi D^2/4$).

Step 3: Determine *q/Q* to find partial flow elements *d/D* and *v/V* in Fig. 2, depth of flow (*d*) and actual flowing velocity (*v*) are then calculated. Based on DWF, the minimum allowable velocity to prevent sedimentation in pipes is 0.6 m/s [11].

According to the hydraulic analysis, the operational performance of the SPS is considered to be efficient if the actual flowing velocity (*v*) in the outlet sewer is greater than 0.6 m/s. The actual discharge *q* (calculated based on the operational schedule of the station) should be smaller than outlet sewer design capacity to prevent overflow and *d/D* ratio must be greater than 0.3 [7].

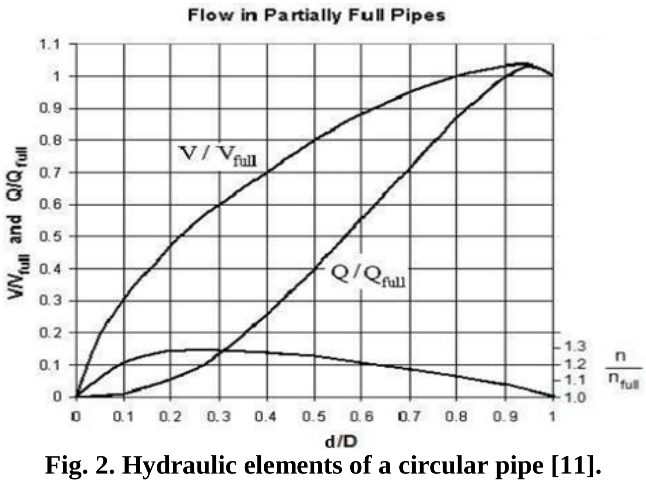

Fig. 2. Hydraulic elements of a circular pipe [11].

3. Results and Discussion

It is clear that the problem of sewage pumping stations lies only in the design of the stations. Some municipalities found that with a well-designed system and periodic maintenance, problems could be greatly reduced. As commented by Davis and Master [12], the importance of the hydraulic design of the sewage pumping stations in operation and maintenance, which depends on the theoretical and practical experience of the operating staff over the years to solve problems immediately.

3.1. Operational schedule

3.1.1 Al-Habibia sewage pumping station

Al-Habibia SPS does not operate on a fill/draw cycle because there is no level control system in the wet wells instead of that the operation is done in such a way that the number of pumps in operation is according to the amount of influent sewage received and staff experience. Five pumps are operated if the elevation of 4 m sewage is reached in the wet wells, more pumps will be turned on and operate for a limited cycle duration if the sewage level increases. In some special cases such as rainy seasons, the sewage level rises to the high sewage alarm elevation of 7 m (4 m of sewage will be over the crown of inlet sewer) leading to the operation of all pumps at the station. In this case, a manual operation control process is performed by the working staff in the station.

The staff works in cooperation with a person standing at a position downstream this SPS on Zublin trunk sewer, which is considered the lowest point on this line. A signal is sent by this person to the working staff when the level of sewage rises (due to the pumps in operation) that may cause overflow in the streets in order to reduce the number of pumps in operation. The manual operation control in Al-Habibia SPS has to be controlled by Programmable Logic Controller (PLC) as an indicator only, so the pumps will operate according to different flowing conditions.

The general operational schedule is shown in Table 1, in which, the actual average flow q for the three cases of operation at (morning, peak time and night) is calculated. In this table, the actual maximum flow for the first case, for example, was calculated as only four pumps of discharge 1.5 m^3/s are in operation giving the maximum discharge capacity in this station. The actual minimum flow was calculated using two pumps of 1 m^3/s and two pumps of 0.5 m^3/s since this configuration gives the minimum discharge flow.

Table 1. The general operational schedule of Al-Habibia SPS with the calculated actual average flow q.

Case	Time	No. of operating pumps	Actual maximum flow (m^3/s)	Actual minimum flow (m^3/s)	Actual average flow q_p (m^3/s)
1	**Morning (6-9) a.m.**	4	$6\ m^3/s$ $(4 \times 1.5\ m^3/s)$	$3\ m^3/s$ $(2 \times 1 \frac{m^3}{s} + 2 \times 0.5 m^3/s)$	$4.5\ m^3/s$
2	**Peak time (9 a.m. - 12 p.m.)**	8	$10\ m^3/s$ $(4 \times 1.5\ m^3/s + 4 \times 1 m^3/s)$	$8\ m^3/s$ $(2 \times 1.5\ m^3/s + 4 \times 1 m^3/s + 2 \times 0.5\ m^3/s)$	$9\ m^3/s$
3	**Night (12 p.m. - 9 a.m.)**	2	$3\ m^3/s$ $(2 \times 1.5\ m^3/s)$	$1\ m^3/s$ $(2 \times 0.5\ m^3/s)$	$2\ m^3/s$

3.1.2. Al-Ghazali sewage pumping station

Similar to Al-Habibia SPS, as there is no level control system in the wet wells, the operation of Al-Ghazali SPS is done by the staff experience. The number of pumps in operation is according to the amount of the influent sewage received and sewage level in the wet well. This station has two pumps of discharge 1.5 m^3/s and three pumps of 1 m^3/s, the general operational schedule is shown in Table 2. This table shows that at peak flow condition only two pumps are operated, although there are five pumps in the station. Not all of the pumps are used as the sewer cannot receive all the sewage flow from Al-Ghazali SPS due to the presence of sediments in the Baghdad trunk sewer. The flowing capacity of this sewer has been reduced by 70% of the cross-section area by these sediments.

The presence of solids in sewerage systems has always led to problems such as reduced hydraulic capacity, increased incremental cost, floods, gases, odors, and explosions resulting from biological degradation of household sediments (hydrogen sulphate, methane and other substances with odor), sewer corrosion generated from biological degradation in bed deposits in moist atmosphere, pump impeller abrasion by inorganic solids in the flow, shock loads in treatment plants and health risk to sewer workers [6].

Table 2. The general operational schedule of Al-Ghazali SPS with the calculated actual average flow q.

Case	Time	No. of operating pumps	Actual maximum flow (m^3/s)	Actual minimum flow (m^3/s)	Actual average flow q_p (m^3/s)
1	**Morning (6-9) a.m.**	2	$2.5\ m^3/s$ $(1 \times 1.5\ m^3/s\ + 1 \times 1m^3/s)$	$2\ m^3/s$ $(2 \times 1\ m^3/s)$	$2.25\ m^3/s$
2	**Peak time (9 a.m.-12 p.m.)**	2	-	-	$2.5\ m^3/s(1 \times 1.5m^3/s$ $+1 \times 1m^3/s)$
3	**Night (12 p.m. -9 a.m.)**	1	-	-	$1\ m^3/s(1 \times 1\ m^3/s)$

3.2. Hydraulic analysis of Al-Habibia sewage pumping station

3.2.1. Influent sewer

The influent sewer to Al- Habibia SPS is a concrete sewer of 3 m diameter with 0.0025 m/m slope and roughness coefficient (n = 0.013). According to Manning's formula Eq. (1) and (2) the full flow discharge and velocity are Q = 22.4287 m^3/s and V = 3.175 m/s respectively.

To study the effect of the operational performance of this sewage pumping station on the influent sewer, three cases of influent sewage flow must be determined. These cases include *d/D* equal to 0.3, 0.5 and 0.75 and their corresponding *q/Q* 0.14, 0.42 and 0.78 as shown in Fig. 2, which represent low, medium and high flow respectively. The influent flow q_{in} (that is calculated for the three cases) and the three operational conditions of this SPS (q_p) are shown in Table 3.

It appears from Table 3, that for the low and medium flow conditions, the discharge of the pump q_p is less than the inlet flow q_{in}. These cases can be solved by running more pumps to discharge the inlet flow. As the overall design capacity of the station is 11 m^3/s, it can deal with these flow conditions. However, for the high flow condition, the inlet flow is greater than the design capacity 11 m^3/s, here a problem of backup flow may occur in the inlet sewer leading to sewer overflow and flooding [10].

Table 3. The hydraulic characteristics of influent sewer (q_{in}) and corresponding pumps outlets of Al-Habibia SPS.

Case	q_{in} (m^3/s)	q_p (m^3/s)
Low	3.14	2
Medium	9.42	9
High	17.495	4.5

3.2.2. Effluent sewer

This pipe is a concrete sewer and has the same characteristics of the inlet pipe (3 m diameter with 0.0025 m/m slope). The hydraulic elements of partial flow for all operating conditions are shown in Table 4. The results of this table indicate that the actual flowing velocities for the three cases are greater than the minimum allowable velocity (0.6 m/s) for DWF [11].

Table 4. Hydraulic properties for the outlet sewer of Al-Habibia SPS.

Case	Q (m^3/s)	q_p (m^3/s)	q/Q	d/D	D (m)	v/V	V (m/s)
1	22.4287	4.5	0.2	0.363	1.089	0.67	2.127
2	22.4287	9	0.4	0.49	1.47	0.78	2.477
3	22.4287	2	0.1	0.3	0.9	0.6	1.905

3.3. Hydraulic analysis of Al-Ghazali sewage pumping station

3.3.1. Influent sewer

This sewer is a concrete pipe 1.6 m in diameter with 0.0008 m/m slope and roughness coefficient (n = 0.013). Using manning's formula, the full flow discharge and velocity are Q = 2.366 m^3/s and V = 1.178 m/s respectively. The three cases of influent flow (low, medium and high) with their corresponding pumps discharge from Table 2 are shown in Table 5. This table indicates that in this station q_p is greater than the influent flow q_{in} for all flow conditions.

Table 5. The hydraulic characteristics of influent sewer (q_{in}) and corresponding pumps outlets of Al-Ghazali SPS.

Case	q_{in} (m^3/s)	q_p (m^3/s)
Low	0.331	1
Medium	0.994	2.25
High	1.845	2.5

3.3.2. Effluent sewer

This sewer is a concrete pipe of 1.85 -m diameter and 0.0008 m/m slope. Then, the full flow discharge and velocity according to Manning's formula are Q = 3.486 m^3/s and V = 1.298 m/s respectively.

It was indicated from site investigation and information from Baghdad Mayoralty that due to the lack of periodical maintenance and cleaning of Baghdad trunk sewer and misuse by the citizens, the deposits accumulated in large quantities in this sewer and reduced its capacity by 70%. To calculate the real discharge (excluding sediments volume) that this sewer can transfer, Eqs. (3) to (5) are used [13]:

$$A = r^2\left(\theta - \frac{sin\,2\theta}{2}\right) \quad (3)$$

$$P = 2r\theta \quad (4)$$

$$R_h = \frac{A}{P} \quad (5)$$

where A is a wetted area, P wetted perimeter, r radius of the pipe, 2α angle subtended by water surface AC at the center and R_h hydraulic radius. Figure 3 shows a circular sewer through which, sewage is flowing ($q_{70\%}$) when 70% of vertical diameter is immersed.

$$\cos\alpha = \frac{OB}{OC} = \frac{0.925 - 0.555}{0.925} = 0.4$$

$$\alpha = 66.422°$$

$$\theta = 180° - \alpha = 180° - 66.422° = 113.578°$$

$$\theta = 113.578° \times \frac{\pi}{180} = 1.982\ rad$$

$$A = 0.925^2\left(1.982 - \frac{\sin(2 \times 113.578)}{2}\right) = 2\ m^2$$

$$P = 2 \times 0.925 \times 1.982 = 3.667\ m$$

$$R_h = \frac{2}{3.667} = 0.545$$

$$q_{70\%} = \frac{1}{0.013} \times 2 \times 0.545^{\frac{2}{3}} \times 0.0008^{\frac{1}{2}} = 2.903\ m^3/s$$

$$q_{real} = Q - q_{70\%} = 3.486 - 2.903 = 0.583\ m^3/s$$

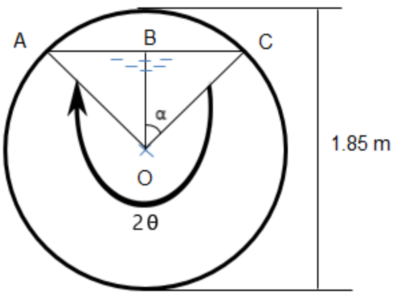

Fig. 3. Definition sketch of real or partial flow for circular pipes.

The actual sewage flow (q_{real}) that the effluent sewer can transfer for the three cases of operation as shown in Table 6. It can be observed from this table that $q_p > q_{real}$ for all cases, this means that the pumps will discharge sewage flow more than the capacity of the effluent sewer. Once the sewer has reached its full capacity or becomes overloaded, sewage flows at much higher water level than normal and causing manholes to pop open releasing sewage onto the streets. When overflow occurs, public health will be at risk and environmental regulations are violated.

Table 6. The hydraulic characteristics of effluent sewer and corresponding pumps outlets of Al-Ghazali SPS.

Case	$q_{real}(\mathrm{m^3/s})$	$q_p(\mathrm{m^3/s})$
Low	0.583	2.25
Medium	0.583	2.5
High	0.583	1

4. Conclusions

In this study, the operational performance of the two main sewage pumping stations was evaluated and its effect on trunk sewer deterioration was investigated using the hydraulic analysis. Based on the completed evaluation of the sewage pumping stations, the following points were concluded:

- From site investigation, the pumps of the two selected case studies are observed to be in good condition and are able of providing many more working years of service since most of them are recently replaced. However, level switches and controls are out of order in these stations, which need to work at optimum conditions.
- For the influent sewer of Al-Habibia SPS, at high sewage flows into the SPS (d/D=0.75), the pumps cannot drain it since it exceeds its design capacity. Thus, backup occurs in the inlet sewer and causes flooding. The hydraulic analysis for the effluent sewer showed that the actual flowing velocities of the operating conditions examined were greater than the minimum self-cleaning velocity (0.6 m/s). More pumps should be added in this station for handling high sewage flow.
- For Al-Ghazali SPS, it is able to receive the influent sewage for all the cases of flow (low, medium and high). While, the effluent sewer that was 70% filled with sediments, that reduced its capacity, it could not deal with the high discharges of the pumps. Therefore, sewage flows from this overloaded sewer on to the streets and harms the environment.
- To avoid `many problems in the sewerage system including sewage pumping stations routine inspections and condition analysis is required. Continues maintenance should be performed to keep the system working efficiently.

Nomenclatures

A	Wetted area, m^2
D	Pipe diameter, m
d	Depth of flow, m
n	Roughness coefficient
P	Wetted perimeter, m
Q	Full flow discharge, m^3/s
q	Partial flow discharge, m^3/s
R	Hydraulic radius, m
r	Radius of the pipe, m
S	Longitudinal slope, m/m
V	Full flow velocity, m/s
v	Actual flowing velocity, m/s

Greek Symbols

2α	Angle subtended by water surface at center

Abbreviations

DWF	Dry Weather Flow
PLC	Programmable Logic Controller
SPS	Sewage Pumping Station
STP	Sewage Treatment Plant
WWF	Wet Weather Flow (q)

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