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USING DISCRETE-EVENT SIMULATION TO EVALUATE A NEW MASTER PLAN FOR A SANITARY INFRASTRUCTURE

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ABSTRACT

Increasing population and changes in life style have caused the wastewater network to deteriorate while exceeding their designed capacities. The Ministry of Public Works (MPW) is planning on expanding the capacities of some treatment plants and demolishing and replacing others with new ones by 2045. To asses this expansion, the current wastewater network was analyzed and the amount of untreated sewage water that is dumped into the sea was taken into consideration. The current network is composed of twelve main pumping stations and four treatment plants. Using discrete- event simulation, the current and future situations were modeled and the outputs were compared. This gives us a valid base to give recommendations for this large infrastructure project.

1 INTRODUCTION

Kuwait is a peninsula that is surrounded by the Arabian Sea, also known as the Persian Sea. According to Aleisa et al. (2011), administrators established wastewater networks in the State of Kuwait around the 1950's. In 1984, these secondary treatments were upgraded to tertiary treatments. In 2005, Sulaibiya Treatment Plant was established to become the largest treatment plant in the world that treats wastewater using Reverse Osmosis (RO) technology. Currently, Sulaibiya treatment plant treats about 64 percent of the entire sewage network. Furthermore, Jahra, Umm Al-Hayman, and Riqqa Treatment plants are facing problems due to the fact that their designed capacities have been exceeded. In Kuwait, the sanitary network is composed of twelve pumping stations and four main treatment plants. Increasing population and changes in lifestyle is causing crucial problems in the current wastewater network. The Ministry of Public Works, has suggested a Master Plan for a new sewage treatment system, that is going to take place in 2045. The current network and the future network are going to be analyzed through Arena Software. Discrete-Event Simulation (DES) has been used to estimate capacities, analyze, and balance effluent water flows (Andreottola et al. 1997; Batstone et al. 1997; Filali-Meknassi et al. 2005; Langergraber 2007; Muschalla et al. 2008; Samuelsson et al. 2001). Furthermore, Ceric (1993) used DES in Zagreb, Croatia to model a solid waste processing system. Moreover, Ferrer et al. (2008) designed a software that is used to design, simulate and optimize wastewater treatment plants.

2 DATA COLLRCTION AND ANALYSIS

In Kuwait, the wastewater network consists of twelve pumping stations; A's, and four treatment plants; Sulaibiya, Riqqa, Um Al-Hayman, and Jahra. Sulaibiya is the newest treatment plant that produces RO water. Furthermore, there are also small pumping stations; P's, and screw lifting stations; S's, which are connected to the main pumping stations.

The daily flow rate data, in cubic meters, for 2009 and 2010 was obtained for each treatment plant and the main pumping stations. The flow rates that were analyzed plotted as time series plots. In addition, the capacities and geographic locations are obtained for both the treatment plants and the pumping stations, which are shown in Table 1 and Table 2 respectively.

Table 1: Wastewater Treatment Plants' Capacities and Locations

Treatment Plant	Capacity (m^3/day)	Average Flow (m^3/day)	Location	
			North	*East*
Sulaibiya	425,000	276,843	29°15'57.94"N	47°43'40.80"E
Jahra	150,000	116,284	29°19'36.29"N	47°43'50.31"E
Riqqa	180,000	168,774	29° 9'8.42"N	48° 4'0.08"E
Umm Al-Hayman	27,000	17,578	28°52'19.95"N	48°12'47.37"E

2.1 General Remarks on the Current Network:

Kuwaits' sanitary network is facing critical problems due to the mal function of Mishref pumping station in which 175,000 m^3 per day is being dumped into the sea. Furthermore, rainfalls increase the flow level of the wastewater in the network in which the pipelines are already full. Therefore, shutdowns occur and the sewage water gets dumped into the sea. Sometimes, electricity failure and unexpected shutdowns occur, causing the water to be disposed in the sea. Moreover, large amounts of purified water are being dumped in the sea. Also, Jahra and Riqqa treatment plants are located in residential areas. Umm Al-Hayman receives untreated water from 240 tanks per day; three out of ten are rejected because they do not meet the plant's specifications.

Table 2: Pumping Stations' Capacities and Locations

Pumping station		Capacity (m^3/day)	Average Flow (m^3/day)	Location	
				North	*East*
ZONE (1)	A3	172,800	58319	29°22'0.06"N	48° 0'38.87"E
	A4	69,120	19171	29°23'0.95"N	47°59'40.65"E
	A6	172,800	123988	29°21'37.20"N	47°57'37.59"E
	A7	288,000	148067	29°20'52.43"N	47°56'31.82"E
	A8	17,420	3550	29°19'59.01"N	47°54'25.19"E
	A9	211,200	72764	29°17'55.39"N	47°55'34.81"E
	A12	126,000	90483	29°17'10.76"N	47°55'38.11"E
ZONE (2)	A14	176,400	138187	29° 7'37.37"N	48° 8'2.23"E
	A15	328,320	211887	29° 7'56.39"N	48° 7'34.41"E
	A18	100,800	55615	29°21'4.95"N	47°41'27.82"E
	A19	208,000	35375	29°18'36.34"N	47°50'2.19"E
	A20	48,080	12984	28°54'36.23"N	48°13'4.14"E

3 SIMULATION MODEL

Simulation was chosen because it has the ability to compare the existing situation with the Future plan given to stochastic behavior and seasonality involved. Arena Input Analyzer was used to fit the daily flow rates into statistical distributions. In the model, each entity was discretized to 1,000 m^3. Each simulation replication consistence of 365 days. Ten replications were used to maintain an error below five percent. Figure 1 shows the flow of the network and Figure 2 shows the corresponding simulation model in Arena software, while Table 3 summarizes the pumping stations' distributions.

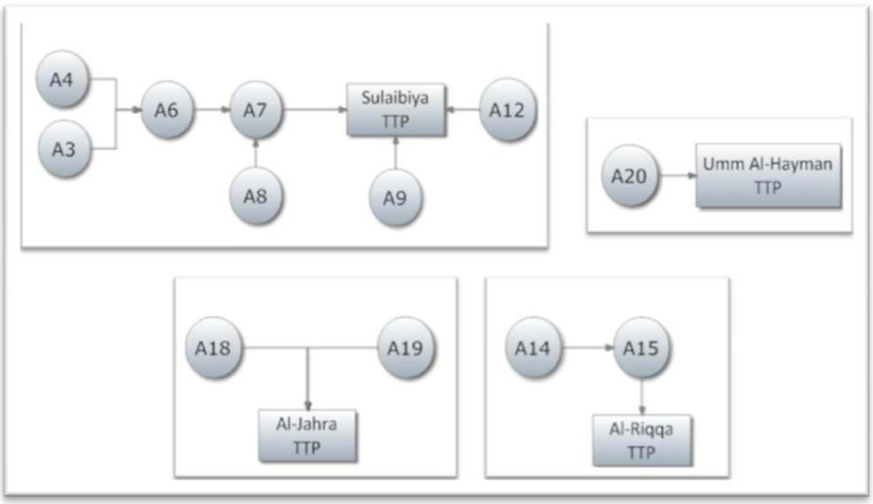


Figure 1: Drawing of the Networks

Table 3: Statistical Distributions for Pumping Stations

Station	Distribution	Station	Distribution
A3	NORM(5.83e+004, 3.59e+003) Square Error: 0.030145	A12	NORM(9.05e+004, 1.24e+004) Square Error: 0.148262
A4	NORM(1.92e+004, 1.89e+003) Square Error: 0.016721	A14	NORM(1.38e+005, 3.77e+003) Square Error: 0.007789
A6	9.45e+004 + WEIB(3.18e+004, 4.14) Square Error: 0.008776	A15	: NORM(2.12e+005, 8.6e+003) Square Error: 0.005994
A6 Over-flow	3.38e+004 + 2.51e+004 * BETA(2.17, 2.12) Square Error: 0.006839	A15 Over-flow	4.74e+004 + 8.58e+004 * BETA(9.88, 22.4) Square Error: 0.007194
A7	1.2e+005 + 5.38e+004 * BETA(6.79, 6.44) Square Error: 0.006670	A18	5.44e+004 + ERLA(314, 4) Square Error: 0.003704
A7 Over-flow	NORM(2.05e+004, 4.55e+003) Square Error: 0.003297	A19	3.31e+004 + 3.78e+003 * BETA(15.6, 10) Square Error: 0.011357
A8	NORM(3.55e+003, 440) Square Error: 0.009516	Jahra over-flow	NORM(2.54e+004, 2.91e+003) Square Error: 0.065338
A9	.58e+004 + 6.03e+004 * BETA(17.3, 10.9) Square Error: 0.041131	A20	1.08e+004 + WEIB(2.41e+003, 1.91) Square Error: 0.003456

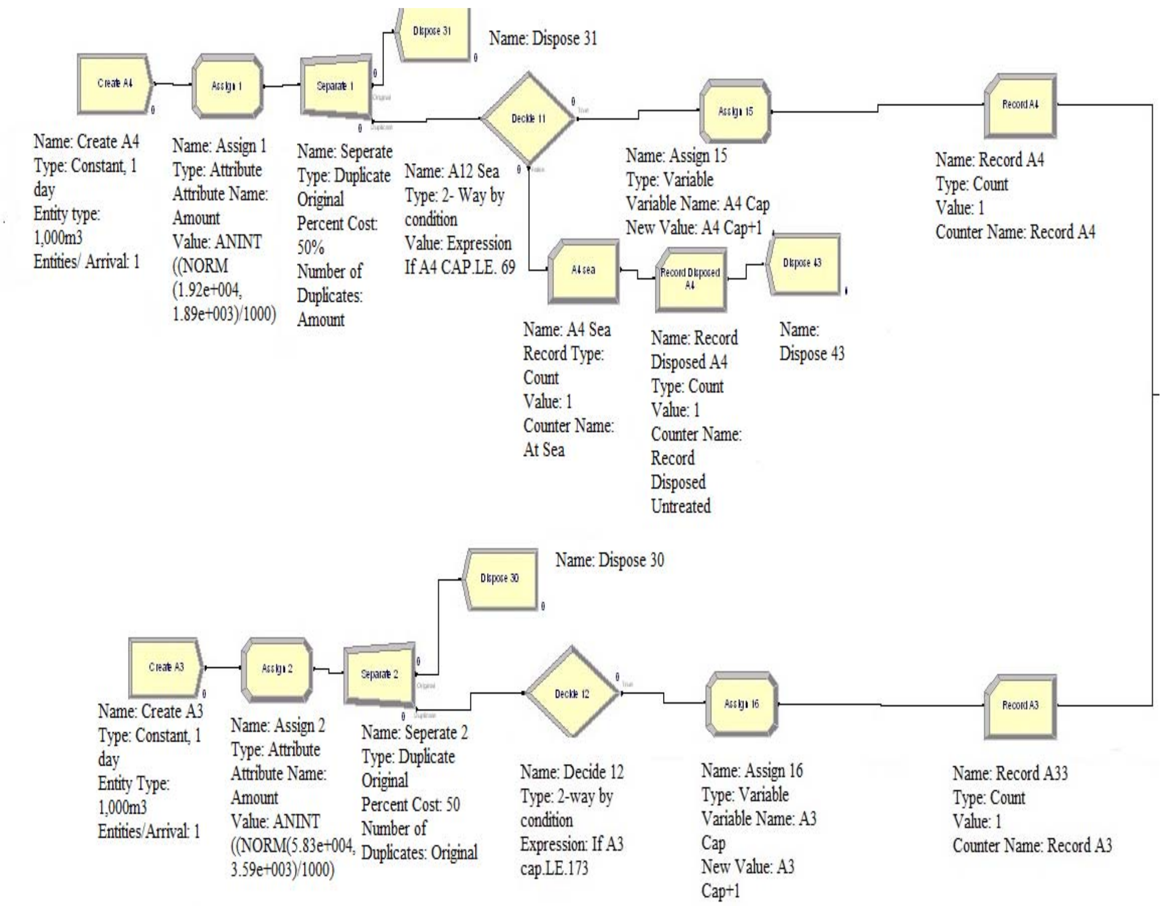


Figure 2: Snap shot of the Simulation Model of the Sanitary System using Arena Software

4 VALIDATION OF THE AS-IS MODEL

The validation process ensures that the simulation model is a valid representation of reality. Table 4 summarizes the actual data for the four treatment plants for a one year period. The results for the validation are shown in table 5. These results were tested against the actual TTP's quarterly data, where the seasonality effect is ignored. This was done because the data was available for one year only.

Table 4: Wastewater Treatment Plants' Actual Data (m3/day)

Quarter Average	Sulaibiya	Jahra (2010)	Riqqa (2009)	Umm Al-Hayman (2009)
Jan. to Mar.	269145 (2010)	118924.0667	167932	16300
Apr. to Jun.	376592 (2010)	115521.2088	171219	17592
Jul. to Sep.	274171 (2010)	115215.2609	165522	16525
Oct. to Dec.	282583 (2009)	115137.4262	170432	19869

Table 5: Wastewater Treatment Plants' Arena Output

Replication	Sulaibiya TTP	Jahra TTP	record Riqqa TTP	record Umm AL Hayman TTP
Replication #1	311456	115989	181000	19956
Replication #2	311633	116867	181000	20089
Replication #3	311444	116400	181000	20033
Replication #4	310344	116144	181000	19911

$X_{1,\ \text{actual Sulaibiya}} = 300623\ m^3/day$

$X_{2,\ \text{model sulaibiya}} = 311219\ m^3/day$

$S_{1,\ \text{actual Sulaibiya}} = 50949\ m^3/day$

$S_{2,\ \text{model Sulaibiya}} = 590\ m^3/day$
$n_1 = n_2 = 4$ replications
$\alpha = 0.05$

Comparing the equality of the population means of the real and simulated population means using population difference confi-dence Intervals of Minitab Software (Two sample *t*-test) yields:

$$-91320 \leq \mu_1 - \mu_2 \leq 70126\ m^3/day \quad (1)$$

This result indicates that the means of these two populations statistically equal at a 95% confidence level. In other words, the simulation is a valid representation of the real system. The *t*-distribution critical value is -0.42 while the P-value is 0.704. Similar analyses were conducted to all WWTPs. All were validated at $\alpha = 0.05$. Table 6 summarizes pumping stations' distributions. Furthermore, the same was done for Jahra, Umm Al-Hayman and Riqqa.

5 DESCRIPTION OF KUWAIT'S FUTURE SANITARY PLAN

The Ministry of Public Works proposed a plan that will take place in 2045. In the New Master Plan, the sewage network is going to be divided into four sub-networks. The following are descriptions of the networks:

- Sulaibiya network will contain two pumping stations, Mishref pumping station and Riggae pumping station (PS). Riggae PS is going to replace A3, A4, A6, A7, A8, A9, and A12. Mishref pumping station, which will be working by then, is going to cover the east part of Kuwait City and Hawalli governorates. These two pumping stations will pump the untreated sewage water to Ardeya, and Ardeya will pump the sewage to Sulaibiya TTP. Sulaibiya TTP will have expansions to ensure that all sewage water is treated. After the water is treated, it will go to the Data Monitoring Control Center (DMC). The DMC will distribute the water between Abdali, Wafra, Sulaibiya Farms, Jahra Birds Reserve, etc.
- Kabd TTP, which will be replacing Jahra TTP, will be receiving untreated sewage water from only one pumping station, Jahra pumping station. The treated water will be pumped to the Data Monitoring Control Unit (DMC). The future network flow of the two treatment plants is shown in Figure 3.

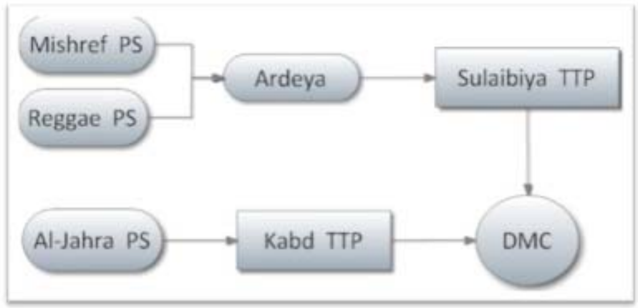


Figure 3: Future Network of Jahra and Sulaibiya Treatment Plants

- Umm Al Hayman TTP, which is going to have an expansion by 2045, will receive sewage water from two pumping stations, Egaela Pumping station and A20. Egaela Pumping Station is a new pumping station that is going to replace A14 and A15. Figure 4 shows the future network of Umm Al-Hayman TTP.

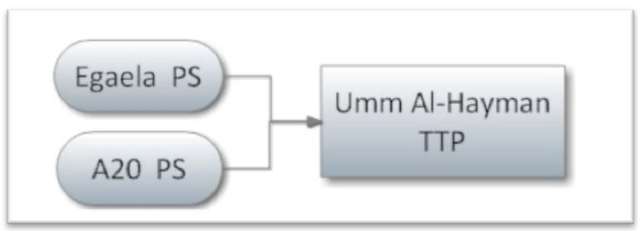


Figure 4: Future Network of Umm Al-Hayman Treatment Plant

- A new treatment plant, Khiran TTP, will be constructed in Khiran, since Khiran is expected to become a residential area. This treatment plant will serve the south coastal strip of Kuwait and will be receiving water from S's and P's.

The future pumping stations and their corresponding current pumping stations are summarized in **Table** . The available capacities, flow rates and geographical locations of future treatment plants and pumping stations are shown in Tables 8 and 9.

Table 6: Future Pumping stations

Future PS	Corresponding current PSs
Reggae PS	A3, A4, A6, A7, A8, A9 and A12
Jahra PS	A18 and A19
Egaela	A14 and A15

Table 7: The Capacities and Locations of the Future Treatment Plants

Treatment Plant	Capacity (m^3/day)	Expected average flow (m^3/day)	Location	
			North	*East*
Sulaibiya TTP	600,000	930,797	29°14'48.51"N	47°42'53.39"E
Kabd TTP	360,000	239,545	29°12'24.16"N	47°43'7.97"E
Umm Al-Hayman TTP	450,000	383,885	28°52'22.89"N	48°12'36.64"E
Khiran TTP	27,000	-	28°39'36.15"N	48°22'59.13"E

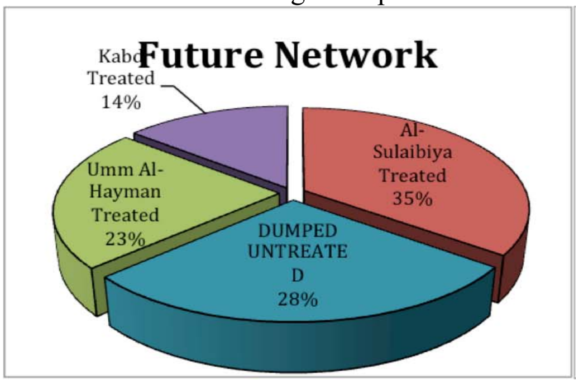
Table 8: The Capacities and Locations of the Future Pumping Stations

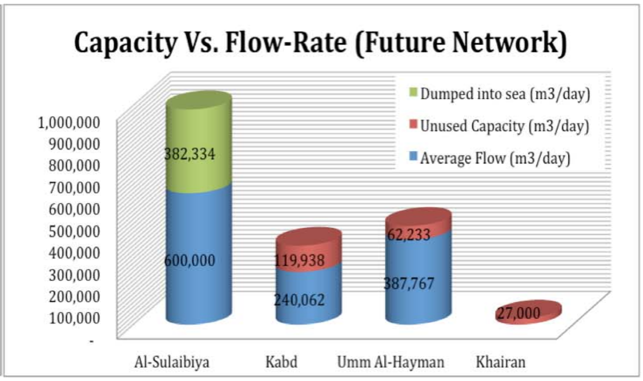
Pumping Station	Capacity (m3/day)	Expected average flow (m^3/day)	Location	
			North	*South*
Mishref PS	340,000	360,500	29°16'10.46"N	48° 4'56.70"E
Reggae PS	777,600	641,307	29°18'33.65"N	47°55'11.14"E
Jahra PS	375,000	239,545	29°19'42.19"N	47°44'8.32"E
Egaela PS	360,000	436,487	29° 9'40.72"N	48° 6'30.31"E
A20 PS	48,080	26,747	28°54'36.09"N	48°13'3.88"E

6 ANALYSIS OF THE FUTURE NETWORK

In 2045, Sulaibiya Treatment Plant will be treating about 35 percent of sewage water. On the other hand, Umm Al-Hayman will be treating about 23 percent, Kabd will be treating about 14 percent, and the rest will remain untreated and dumped directly into the sea. This can be shown in Figure 5 (a).

By 2045, if the master plan is implemented, the daily water disposal in the sea will be 475,000 m^3. It is evident that most of the daily water disposal is from Sulaibiya TTP, which shows that Sulaibiya TTP needs to be expanded. Also, Egaela TTP should be expanded because it will dump about 16 percent of the total amount of sewage dumped in the sea.





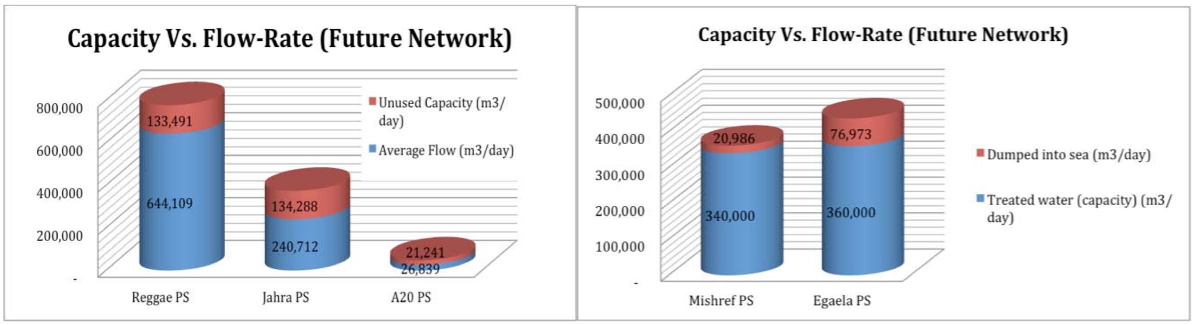
(a) (b)

Figure 5: Capacities and Flowrates of the Treatment Plants

Figure 5 (b) shows that Sulaibiya TTP is going to dump around 382,000 m^3/ day of sewage. This is due to the fact that Sulaibiya TTP is receiving sewage water that is above its designed capacity. As for Kabd TTP, it is running below its designed capacity, while Umm Al-Hayman TTP is on the borderline and therefore it should have its capacity expanded as well.

7 THE STATUS OF THE FUTURE NETWORK'S PUMPING STATIONS

Figure 6 (a) conveys that Mishref and Egaela pumping stations will be dumping sewage water in the sea because they are receiving sewage water greater than their expected capacities. Also, from Figure 6 (b), it is evident that all three pumping stations are currently running below their capacities.



(a) (b)

Figure 6: Capacities vs. Flow-Rate of Pumping Stations

8 CONCLUSION

This research was implemented using simulation to estimate the flow rates and performance of an approved masterplan that is to be commenced by 2045. All major and minor pumping stations national wide was included. Both the existing and future mater was validated to represent reality at a 95 percent confidence level. Forecasted population increase and future water consumptions were included to check how the new sanitary infrastructure will perform in the future after 2045. The simulation helped in developing the following conclusions:

- Mishref pumping station will require a capacity increase to avoid critical problems will arise due to capacity problems.
- Part of Riqqa treatment plant sewage need to be directed to Umm Al- Hayman treatment plant.

The Simulation turned to be an excellent tool to estimate efficiencies and bottlenecks to minimize amounts of untreated sewage water dumped into the sea for such a large infrastructure project.

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