UNDER THE PATRONAGE OF THE EGYPTIAN PRIME MINISTER
11TH WATER DESALINATION CONFERENCE IN THE ARAB COUNTRIES
UNDER THE THEME: NATIONALIZATION OF DESALINATION INDUSTRY IN THE ARAB WORLD
18- 19 April 2017
INTERCONTINENTAL CITY STARS - CAIRO - ARAB REPUBLIC OF EGYPT

Optimum operation policy of Jeddah RO desalination plant under production pumps failure

سياسة التشغيل الأمثل لمحطة جدة لتحلية المياه بالتناضح العكسي تحت إخفاق مضخات الإنتاج

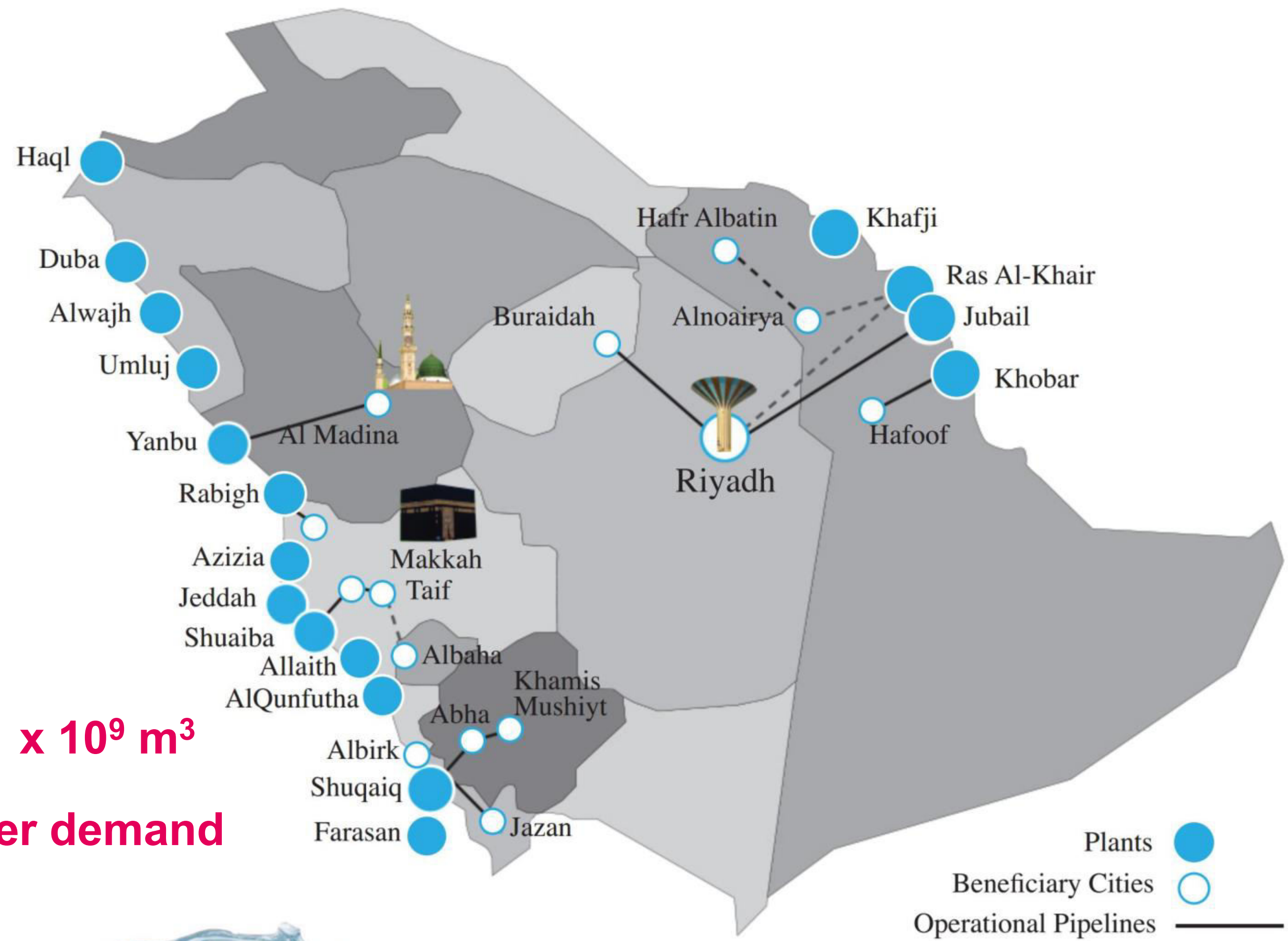
Dr. Khaled Balkhair

Center of Excellence in Desalination Technology
King Abdulaziz University, Saudi Arabia

Content

- Overview
- Jeddah RO plant
- Problem statement
- Objective
- Solution technique
- Results & Analysis
- Conclusions

Desalination Projects in Saudi Arabia



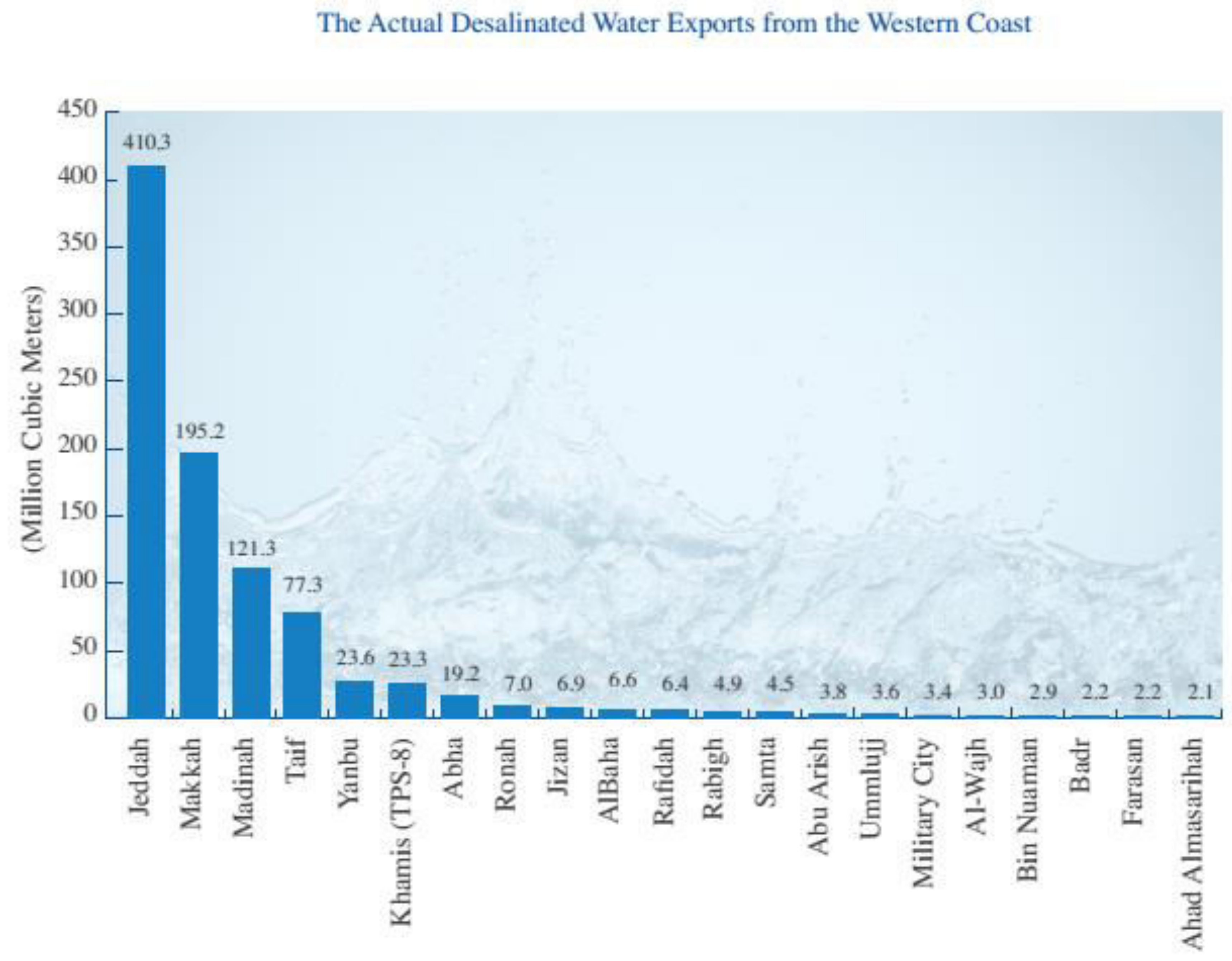
28 Plants

Production = 1.1 x 10^9 m^3

69% of KSA water demand

Design Water Exports and Installed Capacity of SWCC Plants

Plant	Phase	Design Export(m^3)	Installed Capacity(m^3)
Ras Al Khair*	RO	264.450	307.500
Jubail	1	118.447	137.729
	2	815.185	947.890
	RO1	78.182	90.909
	Total of Jubail	1.011.814	1.176.528
Khobar	2	191.780	223.000
	3	240.800	280.000
	Total of Khobar	432.580	503.000
Khafji	1	19.682	22.886
Total Eastern Coast		1.728.526	2.009.914
Jeddah	4	190.555	221.575
	RO1	48.848	56.800
	RO2	48.848	56.800
	RO3	206.400	240.000
	Total of Jeddah	494.651	575.175
Shuaiba	1	191.780	223.000
	2	390.909	454.545
	Total of Shuaiba	582.689	677.545
Yanbu	1	94.625	108.074
	2	120.096	144.000
	RO1	106.904	128.182
	Expansion	58.643	68.190
	Total of Yandu	380.268	448.446
Shuqaiq	1	83.432	97.014


The Actual Desalinated Water Exports from the Western Coast
(Million Cubic Meters)
450
400
350
300
250
200
150
100
50
0
410.3
195.2
121.3
77.3
23.6
23.3
19.2
7.0
6.9
6.6
6.4
4.9
4.5
3.8
3.6
3.4
3.0
2.9
2.2
2.2
2.1
Jeddah
Makkah
Madinah
Taif
Yanbu
Khamis (TPS-8)
Abha
Ronah
Jizan
AlBaha
Rafidah
Rabigh
Samta
Abu Arish
Ummluj
Military City
Al-Wajh
Bin Nuaman
Badr
Farasan
Ahad Almasarihah

Jeddah water strategic storage

No. of reservoirs = 11

Capacity = 188000 m^3/Res.

Total > 2×10^6 m^3

Jeddah RO Plant

Operation : since 1988 .

Number : Three RO Stations.
One MSF Station.

Production : 15 MGD / Station.

Type of membrane : hollow fine fiber .

RO Plants:

Bar Screen

Travelling Screen

Sea Water Pumps

Dual Media Filter

Filter Clear Well Pumps

Micron Cartridge Filter

High Pressure Pumps

Reverse Osmosis Trains

Product Pump

INPUT FLOW TO PRODUCT TANK

1- H.P. Pumps : 10 PUMPS - 676 m^3/H
2- NO. of trains : 10 .
3- Feed pressure : 60 $kg/cm^2.g$
4- Design feed flow per train : 676 m^3/h
5- Design product flow per train : 236 m^3/h
6- Design recovery : 35%
7- Design flow of brine reject : 440 m^3/h

PRODUCT TANK

PRODUCT WATER

1- Back flow tank : 300 m^3

2- Product tank : 700 m^3

3- Product pumps :

4- Capacity : 1193 m^3/h .

MODIFICATION FOR RO TRINS(2008)

ITEMS	BEFORE	AFTER
PRODUCT PUMPS	TWO I/S-ONE S/B	THREE I/S-NO S/B
Input Pressure to Membrane	60 $KG/CM^2.G$	70 $KG/CM^2.G$
Output Product flow from Membrane	236 M^3/H	270 M^3/H
Recovery	35 %	40 %
Brine flow	440 m^3/H	410 M^3/H

PROBLEMS :

1 - Imbalance between input and output (PRODUCT TANK).

2 - Overflow from the reservoir during shutdown of any pump.

OBJECTIVE

Development of cost-effective operation policy for Jeddah RO desalination plant under production pump failure using mathematical optimization approach.

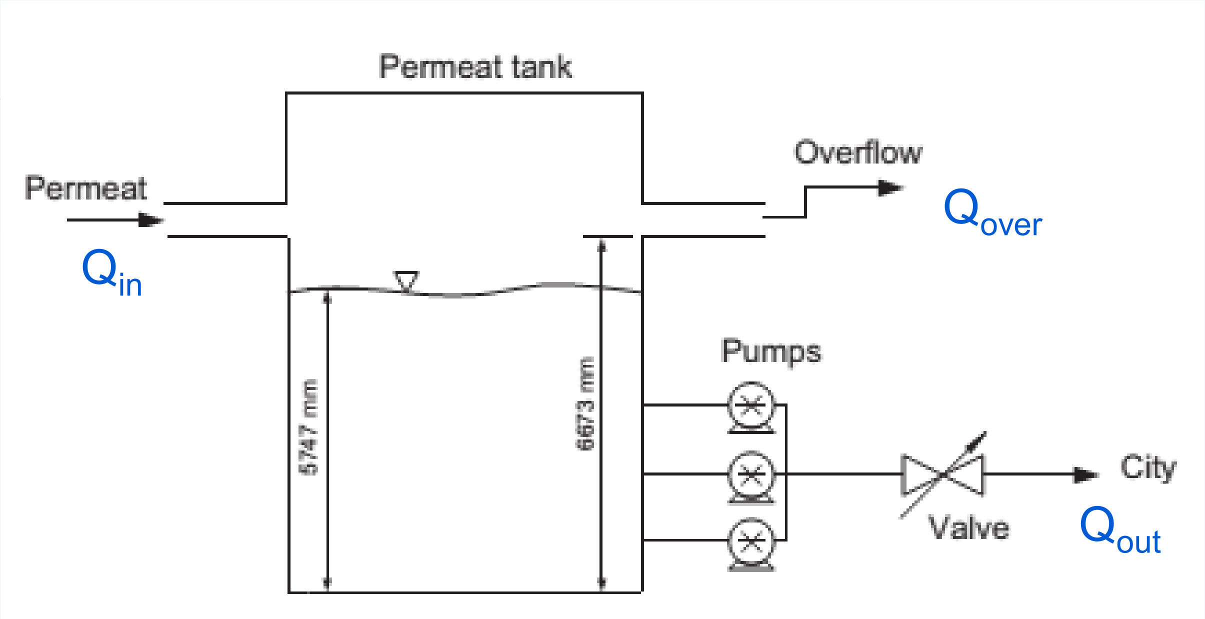
Defects or failure are common …

Malik, A. U., Mobin, M., Andijani, I. N., Al-Fozan, S., & Al-Hamed, A. (2006). **Investigations on the corrosion of flash chamber floor plates in a multistage flash desalination plant**. *Journal of Failure Analysis and Prevention*, *6*(6), 19-24.

Malik, A. U., Al-Fozan, S. A., Al-Muaili, F., & Al-Hajri, M. (2013). **Frequent Failures of Motor Shaft in Seawater Desalination Plant: Some Case Studies**. *Journal of failure analysis and prevention*, *13*(2), 144-152.

Malik, A., Meroufel, A., & Al-Fozan, S. (2015). **Boiler Tubes Failures: A Compendium of Case Studies**. *Journal of Failure Analysis and Prevention*, *15*(2), 246-250.

Problem definition



Permeat input Q_{in} flows into a balance tank that works as a sump to a pumping system consisting of a number of pumps. Pumps discharges water to the city. Due to failure of any of the pumps, tank over flow Q_{over} is wasted back to the sea.

Target solution

Ensure continuous city target supply and stop or minimize overflow under the circumstances of production pump failure.

Problem formulation

Cost-effective operation policy that ensures continuous production during the failure of any production pump.

Mathematical representation

Minimization optimization model

Objective function: $$Min\ Z = \sum_{i=1}^{N} C_i P_i + C_j T_j + M_i P_i$$

Subject to:

Water demand constraint $$\sum_{i=1}^{N} Q_i P_i \geq Q_t$$

Production budget constraint $$Q_{in} - Q_{out} \leq V_j T_j$$

Logical constraint $$T_j \geq 1$$

Nonnegative constraints $$P_i , T_i \geq 0$$

Optimization model

$$Min\ Z = \sum_{i=1}^{N} C_i P_i + C_j T_j + M_i P_i$$

Subject to:

$$\sum_{i=1}^{N} Q_i P_i \geq Q_t$$

$$Q_{in} - Q_{out} \leq V_j T_j$$

$$T_j \geq 1$$

$$P_i , T_i \geq 0$$

C_i = Unit capital cost of pump i;

P_i = No. of pump i;

T_j = No. of tank j;

M_i = Unit cost of power consumption plus maintenance cost;

C_j = Unit cost of tank j;

Q_t = Target flow per unit time;

Q_{in} = Inlet flow per unit time;

Q_{out} = Outlet flow per unit time;

Q_i= Pump i production rate;

V_j = Volume of tank j.

Solution technique

Mixed-integer programming

An **integer programming** problem is a mathematical optimization or feasibility **program** in which some or all of the variables are restricted to be **integers**

The most widely used method for solving integer programs is branch and bound.

Sub-problems are created by restricting the range of the integer variables.

commercial and noncommercial packages to solve mixed-integer linear programming (MILP) are available.

Examples:
POM-QM, ABACUS, BCP, LINDO, BonsaiG, CBC.

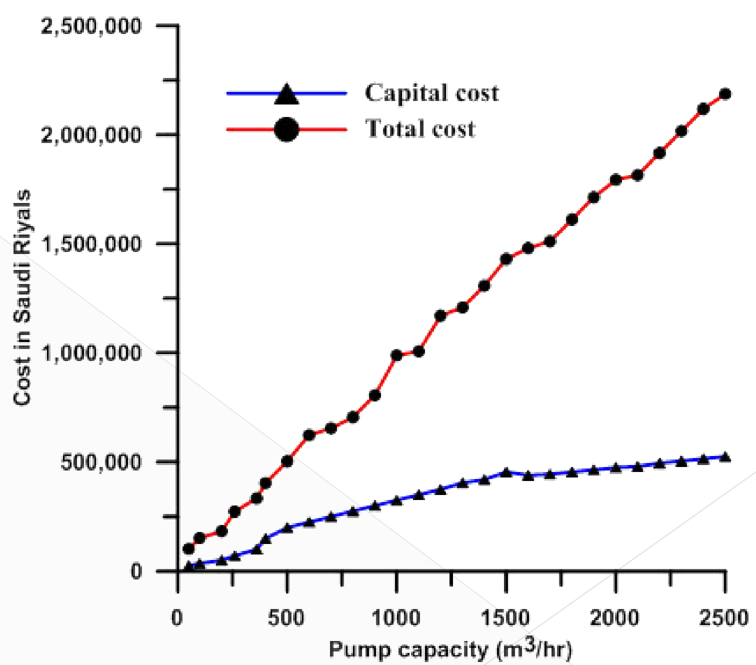
POM-QM: production/operations management, quantitative methods

Objective function parameters

1) capital cost of pump.
2) cost of maintenance and power.
3) cost of Tank.

Capital and total cost of pumps (P_i) and product tank (T_i) available in the local market

Notation variable of pump (P_i)	Discharge capacity (m^3/hr)	Capital cost (SR)	Total cost (SR)
P_1	2500	525,000	2,188,000
P_2	2000	475,000	1,804,000
P_3	1500	435,000	1,431,000
P_4	1200	375,000	1,171,000
P_5	1000	325,000	989,000
P_6	600	225,000	624,000
P_7	360	100,000	333,500
P_8	260	70,000	237,000
P_9	200	50,000	183,500
T_1	1000 (m^3)	340,000	



Plug in numbers …

- $\text{Min } z = 525000P_1 + 475000P_2 + 435000P_3 + 375000P_4 + 325000P_5 + 225000P_6 + 100000P_7 + 70000P_8 + 50000P_9 + 340000T_1$

  S.T

- $2500P_1 + 2000P_2 + 1500P_3 + 1200P_4 + 1000P_5 + 600P_6 + 360P_7 + 260P_8 + 200P_9 \geq 2700$

- $2500P_1 + 2000P_2 + 1500P_3 + 1200P_4 + 1000P_5 + 600P_6 + 360P_7 + 260P_8 + 200P_9 - 1000\ T_1 \leq 2700$

- $T_1 \geq 1$

- $P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, P_9 \geq 0$

Results

Solution summary of the optimization problem under operation and failure of pumps with and with and without power and maintenance costs consideration

Pumps	Solution type	No. of feasible Solutions	No. of pumps	O.F. value x 10^3(RS)	Production rate (m^3/hr)
Operating	Operating pumps No maintenance costs				
P_1	I	1	2	915	2700
	NI	2	1.08 - 1.1	907 - 913	2700
P_4	I	10	2 - 8	2700 - 3000	2700
	NI	142	1.6 - 9	1030 - 1440	2700
Operating pumps with maintenance costs					
P_1	I	1	2	2712	2700
	NI	4	1.08 - 2	2703 - 2765	2700
P_4	I	1	6	2880	2700
	NI	6	1.6 - 7	2824 - 3699	2700
Failure	Power and maintenance costs excluded				
P_1	I	16	2 - 14	1440 - 1915	2700 - 5000
	NI	37	2.04 – 8.22	1411 – 1839.25	2520 - 2610
P_4	I	16	2 - 14	1290 - 1765	2700 - 5000
	NI	37	2.04 – 8.22	1261 – 1689.25	2520 - 2610
Power and maintenance costs included					
P_1	I	47	2 - 14	4882.5 - 6904	2400 - 5000
	NI	83	2.04 – 8.22	4803.52 – 5787. 5	2280 – 2600.5
P_4	I	47	2 - 14	3865.5 - 5887	2400 - 5000
	NI	83	2.04 – 8.22	3786.52 – 4770. 5	2280 – 2600.5

Solution spaces under the operation of P_1

Solution type	No.
Integer	1
Non-integer	2

P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	T_1	Production (m^3/hr)	Value of O.F. x 10^3 (SR)
1	0	0	0	0	0	0	0	1	1	2700	915
1.08	0	0	0	0	0	0	0	0	1	2700	907
1	0.1	0	0	0	0	0	0	0	1	2700	913

1.08 pumps of $P_1 \approx$ one pump with production rate of 2700 (m^3/hr)

0.6 pumps of $P_2 \approx$ one pump with production rate of 200 (m^3/hr)

Pump	Cost (SR)
0.6 x P_2	47,500
P_9	50,000

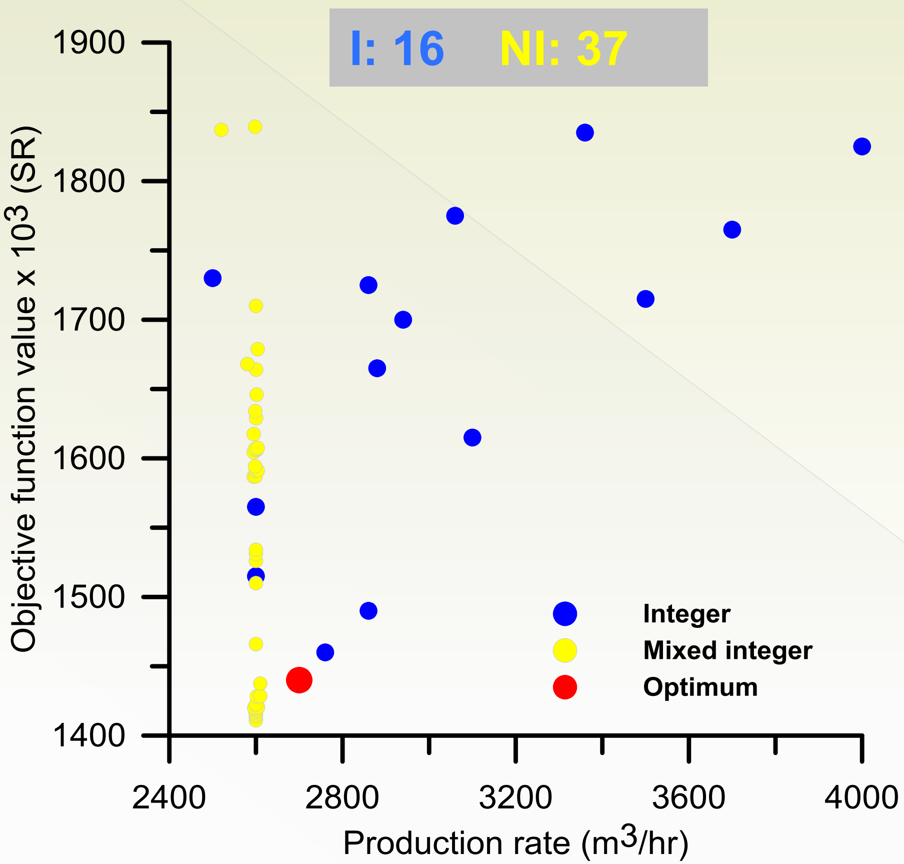
Solution spaces under the operation of P_4

Solution type	No.
Infeasible	16
Integer	10
Non-integer	142

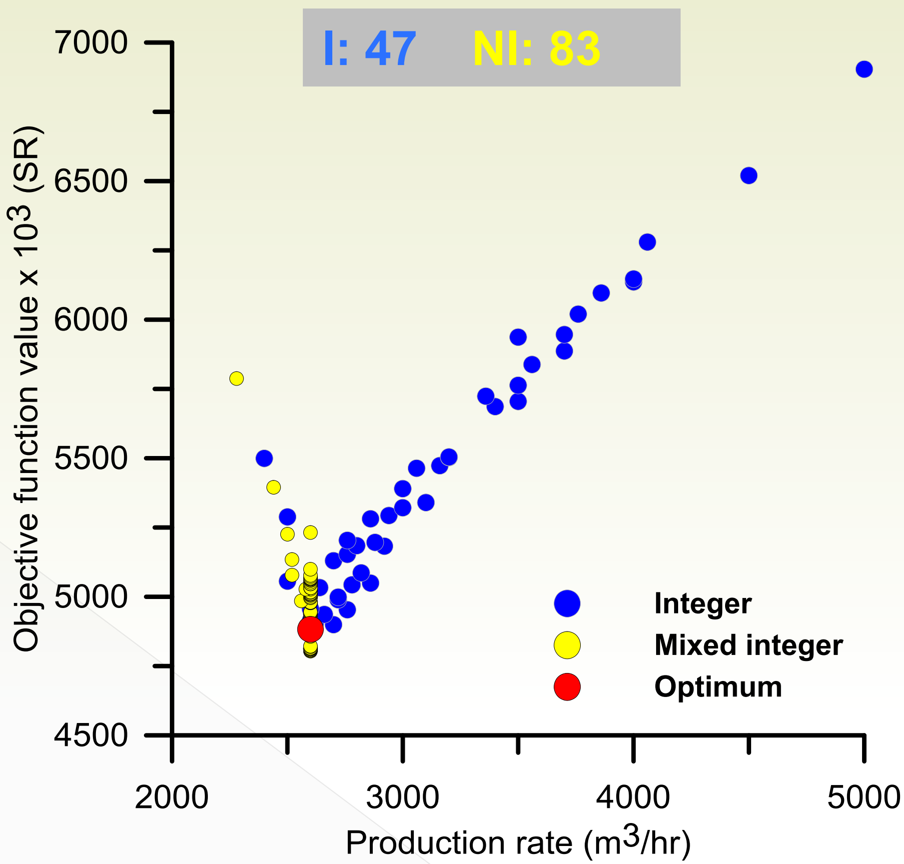
10 < 1.105 x 10^6 SR
& 87 > 1.15 x 10^6 SR

P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	T_1	Production (m^3/hr)	Value of O.F. x 10^3 (SR)
0	0	0	1	0	0	0	2	5	1	2720	1105
0	0	0	1	0	0	2	0	4	1	2720	1115
0	0	0	1	0	0	1	0	6	1	2760	1115
0	0	0	1	0	0	0	5	1	1	2700	1115
0	0	1	1	0	0	0	0	0	1	2700	1150
0	0	0	1	0	1	0	0	5	1	2800	1190
0	0	0	1	1	0	0	0	3	1	2800	1190
0	0	0	2	0	0	0	0	2	1	2800	1190
0	0	0	1	0	2	0	0	2	1	2800	1265
0	0	0	1	0	3	0	0	0	1	3000	1390

Solution spaces

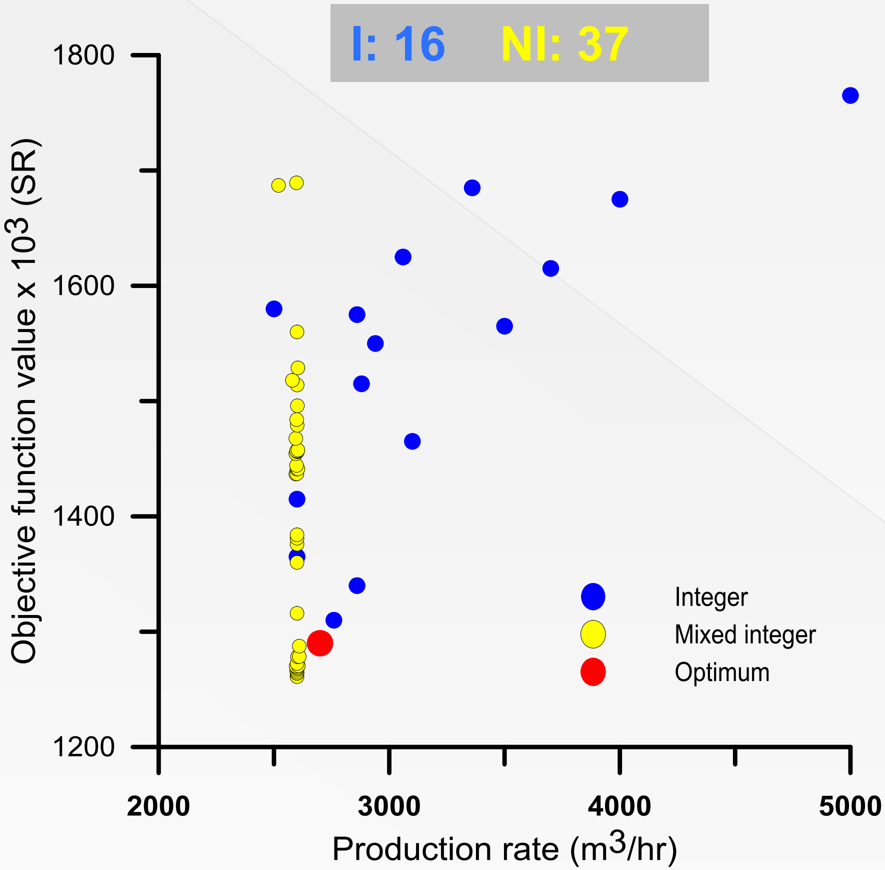


Solution space under the failure of pump P_1 with no consideration of power and maintenance costs.

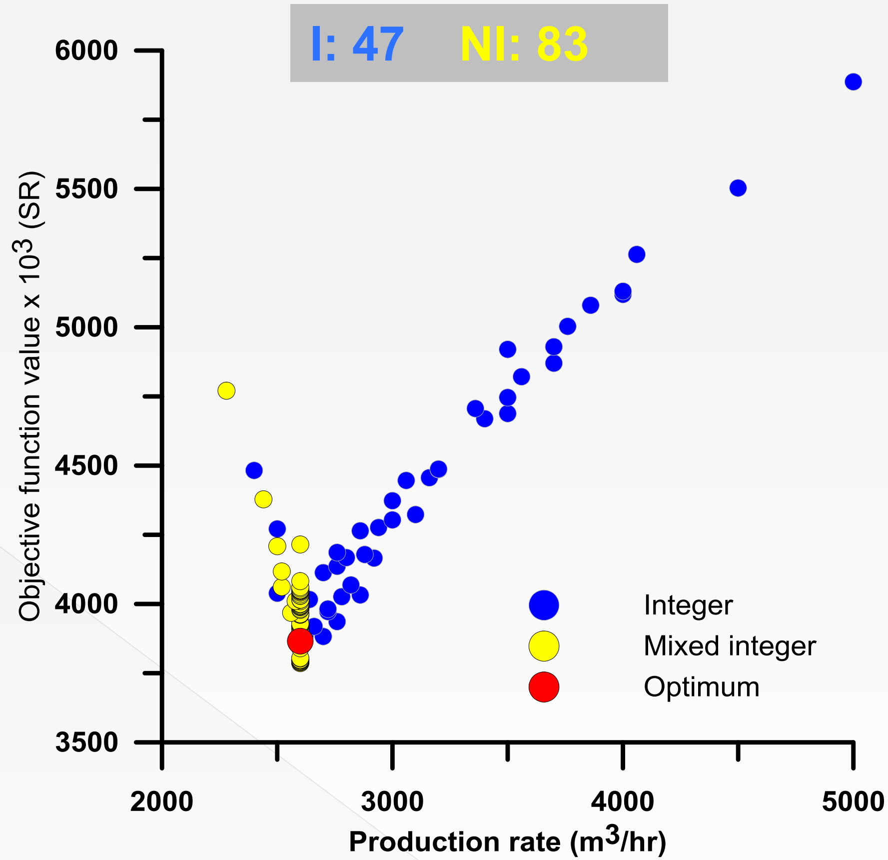


Solution space under the failure of pump P_1 with the consideration of power and maintenance costs.

Solution spaces



Solution space under the failure of pump P4 without the consideration of power and maintenance costs.

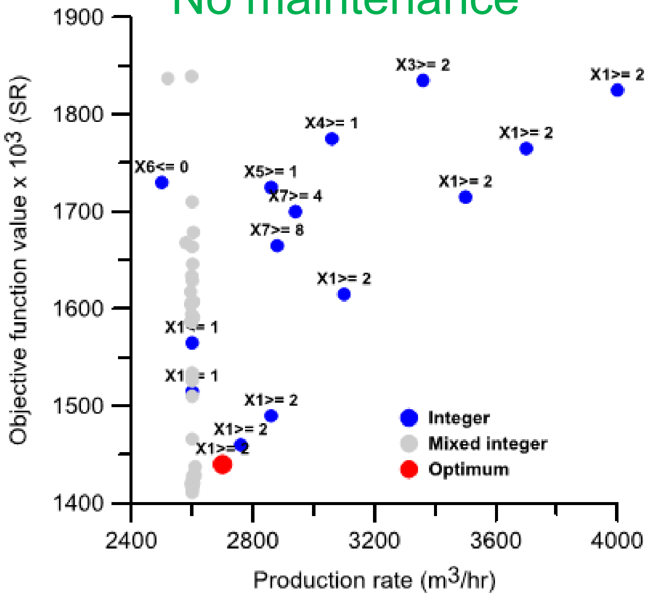


Solution space under the failure of pump P4 with the consideration of power and maintenance costs.

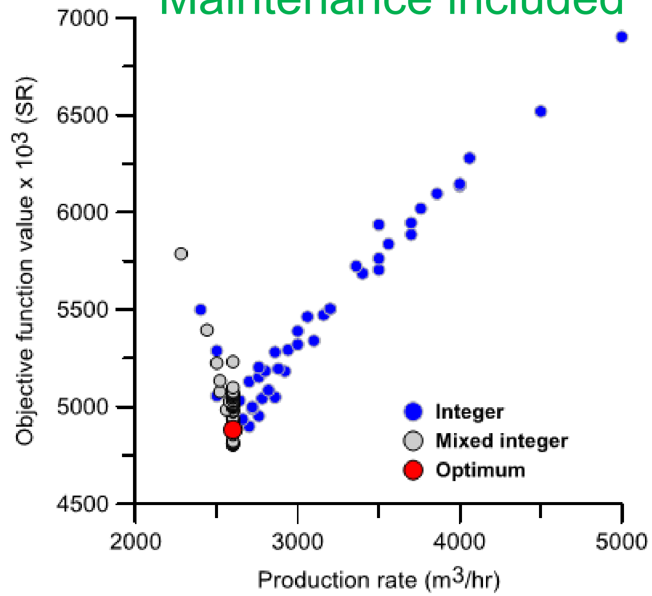
Solution spaces

Case 1

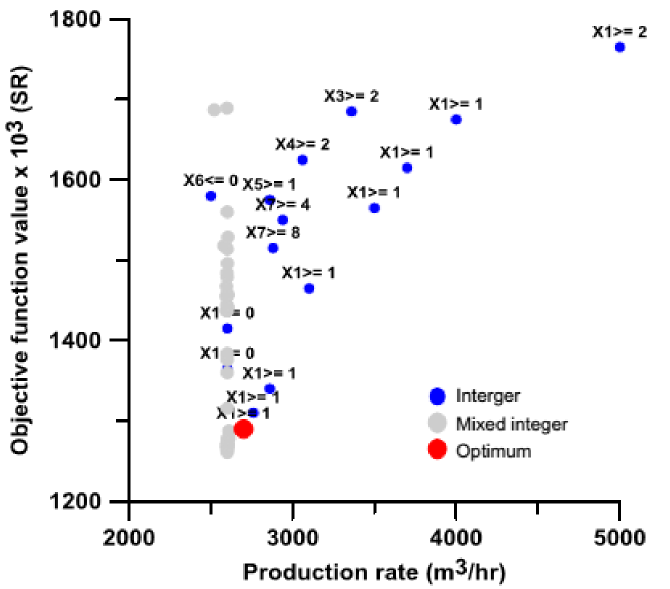
No maintenance

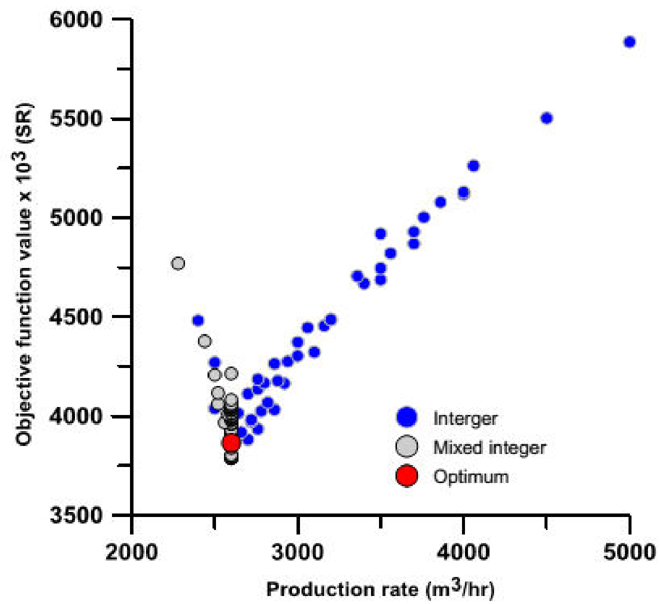


Maintenance included



Case 2





Optimal solutions

POM-QM solves for all feasible, non-feasible, integer, and non-integer solutions

Optimal solutions under normal operating conditions

		No maintenance cost									
Operating pump		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	Value of O.F. x 10^3 (SR)
Integer	P_1	1	0	0	0	0	0	0	0	1	915
	P_4	0	0	1	1	0	0	0	0	0	1150
NI	P_1	1.08	0	0	0	0	0	0	0	0	907
	P_4	0.6	0	0	1	0	0	0	0	0	1030
Operating pump		Maintenance cost included									
Integer	P_1	1	0	0	0	0	0	0	0	1	2712
	P_4	0	1	0	1	0	0	0	0	0	3315
NI	P_1	1.08	0	0	0	0	0	0	0	0	2703
	P_4	0.6	0	0	1	0	0	0	0	0	2824

Optimal solutions under pump failure conditions

Pump failure	Solution type	No. of pumps of type (P_i)									Production rate (m^3/hr)	Value of O.F. x 10^3 (SR)
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9		
Power and maintenance costs excluded												
P_1	I	2	0	0	0	0	0	0	0	1	2700	1440
	NI	2.04	0	0	0	0	0	0	0	0	2600	1411
P_4	I	1	0	0	1	0	0	0	0	1	2700	1290
	NI	1.04	0	0	1	0	0	0	0	0	2600	1261
Power and maintenance costs included												
P_1	I	1	1	0	0	0	0	0	0	3	2600	4882.5
	NI	2.04	0	0	0	0	0	0	0	0	2600	4803.52
P_4	I	0	1	0	1	0	0	0	0	3	2600	3865.5
	NI	1.04	0	0	1	0	0	0	0	0	2600	3786.52

Conclusions

- Mathematical programming proved to be a powerful technique not only in finding an optimal solution for a minimization problem, but also in generating a nearly optimal feasible solution of best operation policy for Jeddah RO desalination plant.
- Cost-effective operation policy has been developed under scenario of normal operation and failure of pumps.
- Inclusion and exclusion of power and maintenance costs produced two different optimal solutions indicating a sensitivity of the operation strategy to the capital and total costs.
- The non-integer number of pumps may be viewed as an integer number with an equivalent production rate that can be customized and manufactured to empower an additional 12–26% reduction in the costs.
- Besides the saving of operation and maintenance costs, the obtained solutions can be adopted to save huge quantities of water production from wasting into the sea.

THANK YOU