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Management of desalinated seawater, wastewater and reclaimed water in insular and geographically isolated areas using optimisation techniques

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ABSTRACT

For the insular areas lacking substantial freshwater resources, the utilisation of alternative water sources, such as desalinated seawater and reclaimed water, is a crucial issue. The use of optimisation techniques can assist in making the right decisions, with respect to water resources management, as the increased complexity, due to various potential solutions, is impending the derivation of the optimal solution. This work presents a mathematical programming approach to optimise water resources management for the island of Syros, Cyclades, Greece. Taking into account the population spread out on the island, and the subsequent localized needs for water use/quality and wastewater production, as well as geographical considerations, the model optimises the location of desalination plants and wastewater treatment and water reclamation plants, as well as the water conveyance infrastructure needed, in order to achieve water management at minimum cost.

Keywords: Water resources management; Desalination; Water reclamation; Optimisation; Mathematical programming

1. Introduction

Due to technological advances in water treatment processes, a number of alternative (non-conventional) water resources are now available for water supply [1], besides the classical options, which include lake and river water, runoff collection in water reservoirs and underground water. Insular areas with limited access to freshwater sources can particularly benefit from alternative water sources, such as desalinated sea water [2], treated brackish water [3], and reclaimed water from wastewater [4]. Small and medium size islands of the Aegean Sea have limited water resources. Large volume of freshwater is often imported from the mainland, or from larger islands, such as Rhodes Island, particularly during summer. Sea water desalination plants have been recently established on some islands, providing high quality of freshwater at relatively high cost [5]. In many islands, water consumption from alternative sources surpasses that from conventional sources. The current primary challenge in water resources management for insular areas is to choose the optimal blend of water sources, at the minimum cost [6].

Recently, a lot of optimisation techniques have been applied in the decision process of the real world water resources management problems. Wang and Jamieson [7] presented an objective approach to regional wastewater treatment planning for the upper Thames basin in the UK, based on the combined use of Genetic Algorithm

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(GA) and Artificial Neural Networks (ANN). Draper et al. [8] presented an economic-engineering optimisation model of California's major water supply system. Later, Medellín-Azuara et al. [9] applied the same economic model to explore and integrate water management alternatives within Ensenada, Mexico. Assimacopoulos [10] presented the evaluation of different scenarios regarding the allocation of water resources and financial, environmental and resource costs in the island of Paros in Greece, based on Decision Support System. Han et al. [11] presented a multi-objective linear programming model to allocate various water resources among multiuser and applied it to obtain the reasonable allocation of water supply and demand in Dalian, China. Joksimovic et al. [12] developed decision support software (DSS) for water treatment for reuse with network distribution, in which a GA approach is used for the best selection of customers, and applied it in the study of industrial water reuse options in Kyjov, Czech Republic.

The objective of this work is to use a mathematical programming approach, based on mixed integer linear programming technique to optimise water resources management for the island of Syros, Greece. The proposed model aims to optimise the allocations, number and capacities of seawater desalination, wastewater treatment and reclamation plants, and the infrastructure needs for water storage and distribution (water and wastewater pipelines and pumping stations), from ground basis.

Fig. 1. Subdivision of Syros island into 6 regions.

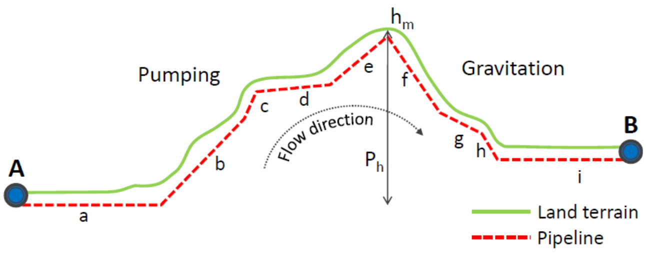

Fig. 2. Schematic graph for the definition of the terms: "distance", "pumping distance" and "pumping elevation" between points "A" and "B", for flow direction A → B: The length of the pipeline between A and B is called "distance" = a+b+c+d+e+f+g+h+i, the length of the pressurized pipeline is called "pumping distance" = a+b+c+d+e, the maximum height that the liquid has to be pumped is called "pumping elevation" = P_h.

2. Problem description

In this problem, we consider the island of Syros, a Greek island in the Cyclades, in the Aegean Sea. On the island of Syros, the limited and low quality ground water resources are almost exclusively used for agricultural irrigation; however, the volume of groundwater is not sufficient to cover all agricultural needs. Desalinated seawater is almost exclusively used for potable and urban uses (such as landscape irrigation). Water reclamation from wastewater is not currently practiced.

For the purposes of the present study, Syros Island has been subdivided into 6 regions, by taking into account population distribution and geographical considerations (Fig. 1). The population centre of Region 1 is at an elevation of 250 m, while for the other regions it has been assumed to be at sea-level. The distances, pumping distances and pumping elevations (see Fig. 2 for definitions of the terms) between the population centres of each couple of regions are given in Table 1.

The daily water demand for each region has been estimated, and has been classified into five categories:

(i) potable water,
(ii) agricultural water (in addition to the existing groundwater),
(iii) landscape irrigation water,
(iv) water for stock raising,
(v) industrial water,

in which (i) can only use potable quality water (desalinated seawater), while the rest can theoretically use any quality of water (desalinated seawater or reclaimed water). In order to satisfy all the water needs, both qualities of water and wastewater are allowed to be freely distributed along most of the regions (Table 1). Water importation is not considered as option, while further exploitation of groundwater is assumed not a feasible option. Water demand and wastewater production varies

Table 1
Distances/pumping distances/pumping elevations between the population centres of each pair of regions (km)

	R1	R2	R3	R4	R5	R6
R1		8/0/0	X	X	X	3.3/0/0
R2	8/8/0.25		5.2/2.3/0.12	9/3.3/0.15	7.3/4/0.18	5.3/3.7/0.26
R3	X	5.2/2.9/0.12		5.3/2/0.02	X	X
R4	X	9/5.7/0.15	5.3/3.3/0.02		5.7/3.7/0.05	X
R5	X	7.3/3.3/0.18	X	5.7/2/0.05		4.2/1.7/0.12
R6	3.3/3.3/0.25	5.3/1.6/0.26	X	X	4.2/2.5/0.12	

X: The link between these regions is a priori not allowed.

Table 2
Estimated water demands (excluding groundwater) and wastewater production in Syros

	Volume per day (High season/Low season) (m^3/d)					
	R1	R2	R3	R4	R5	R6
Potable water demand	150/50	4000/2800	500/250	650/350	500/200	500/300
Non-portable water demand	250/0	900/100	600/50	880/30	580/30	380/30
Wastewater production	150/50	3700/2600	200/100	300/150	300/150	450/250

with season; with high values occurring during summer and lower during winter. Estimated values of seasonal water demand and wastewater production are shown in Table 2. Here are considered two distinct values: high daily volumes which last for 4 months (summer) and low daily volumes, which last for the rest 8 months. A more detailed monthly pattern may be used, if more accurate data are available.

In this problem, the existing infrastructure is not considered. Thus the water resources management is optimised based on ground basis. In this problem, given are:

- regions, pairwise distances of the relative population centres of the regions and elevations;
- potable and non-potable water demands and wastewater production;
- cost of desalinated seawater, treated wastewater and reclaimed water production (additional treatment after wastewater treatment);
- costs of pipelines, as a function of pipe diameter;
- cost of storage tanks, as a function of storage capacity;
- types and costs of pumping stations;
- unit cost of electric power;

to determine:

- allocations, numbers and capacities of desalination, wastewater treatment and reclamation plants;
- pipeline main network for desalinated water, wastewater and reclaimed water, including piping diameters (local piping network is not considered);
- daily volumes of desalinated seawater production, wastewater treatment and reclaimed water;
- main flows of desalinated seawater, wastewater and reclaimed water;
- number, types and operation time of pumps for each established link;

so as to minimise the annualised total cost, including capital cost and operating and maintenance (O&M) cost.

3. Model

3.1. Objective function

The objective in this problem is the minimisation of the annualised total cost, including desalinated seawater production cost, wastewater treatment cost, water reclamation cost, pipeline network capital cost, pumping station capital cost, water storage capital cost, and pumping cost. The objective function is as below:

$$\begin{aligned} \text{OBJ} &= \text{Desalination cost} + \text{Treatment cost} \\ &+ \text{Reclamation cost} + \text{Pumping cost} \\ &+ (\text{Pipeline cost} + \text{Pumping station cost} \\ &+ \text{Storage cost}) \cdot \frac{i \cdot (1+i)^n}{(1+i)^n - 1} \end{aligned} \quad (1)$$

where n is the project life, i is the interest rate, and $\frac{i \cdot (1+i)^n}{(1+i)^n - 1}$ is the Capital Recovery Factor (CRF) [13,14]. In this problem, we consider an interest rate of 5% and a project life of 20 years.

The production cost of desalinated seawater and treatment cost of wastewater and reclaimed include capital, depreciation, energy cost, and O&M cost, as a function of plant capacity. Table 3 gives the unit cost per cubic meter of water.

For the infrastructure decisions, we consider the links/pipes, pumps and storage, which correspond to pipeline cost, pump station cost and storage cost, respectively. There are 4 types of pipes with different diameters and installed costs. Also, 4 types of water pumps and wastewater pumps with different costs, maximum flow rates, and maximum pumping heights are considered. The details of the pipes and pumps are given in Tables 4 and 5.

Each pumping station consists of a pair of pumps (operating and standby); the shell of each pumping station has been assumed to cost US$11000. It has been assumed water storage facilities with retention time of two days (high demand) [6], at a unit cost of US$500/$m^3$ of tank volume.

The operational pumping cost is a function of the pumping elevation, head losses and unit electricity cost (US$0.15/kWh). The head losses have been calculated by the Hazen–Williams equation, in which the flow rates are calculated based on pipe diameters and velocities of water and wastewater, which are 0.8 m/s and 1.0 m/s, respectively.

Table 3
Unit costs of water production and treatment (US$/$m^3$)[a]

Volumetric capacity (m^3/d)	Desalinated seawater	Wastewater	Reclaimed water[b]
100–1000	2.5	0.34	0.30
1000–2500	1.5	0.24	0.18
2500–5000	1.0	0.19	0.17

[a] Adapted from [6]
[b] Additional cost following standard wastewater treatment

Table 4
Unit costs of installed pipes, as a function of pipe diameter[a]

Pipe diameter (in)	2.5	4	6	10
Pipeline cost (installed) (US$/m)	55	60	65	70

[a] Adapted from [6]

3.2. Mass balance and production constraints

Nomenclature

Indices

k, l	— Regions
m	— Piecewise function interval
t	— Season

Sets

K, L	— Set of regions
M	— Set of intervals
T	— Set of seasons
SO_l^{dw}/SI_l^{dw}	— Set of possible sources/sinks of desalinated seawater to/from region l
SO_l^{ww}/SI_l^{ww}	— Set of possible sources/sinks of wastewater to/from region l
SO_l^{yw}/SI_l^{yw}	— Set of possible sources/sinks of reclaimed water to/from region l

Parameters

D_p^{lt}	— Daily demand of potable water in region l during season t
D_{lt}^{np}	— Daily demand of non-potable water in region l during season t
N_l^{dw}	— Maximum allowable number of desalination plants in region l
S_{lt}^{ww}	— Daily wastewater production in region l during season t
θ_m^L	— Lower ends of the interval m
θ_m^U	— Upper ends of the interval m

Continuous variables

P_{lt}^{dw}	— Daily total desalinated water production in region l during season t
$\tilde{P}_{ltm}^{dw}$	— Daily desalinated water production within interval m in region l during season t
Q_{klt}^{dwp}	— Daily flow of desalinated water for potable demand from region k to l during season t

Table 5
Flowrates, costs and maximum pumping heights of water/wastewater pumps

Flowrate (m^3/d)		240	720	1200	2400
Water pump	Pump cost (US$)	5000	10000	14000	19000
	Maximum pumping height (m)	400	400	400	400
Wastewater pump	Pump cost (US$)	6000	9000	28000	56000
	Maximum pumping height (m)	50	50	50	50

Q_{klt}^{dwnp} — Daily flow of desalinated water for non-potable demand from region k to l during season t

Q_{klt}^{rw} — Daily flow of reclaimed water from region k to l during season t

Q_{klt}^{ww} — Daily flow of wastewater from region k to l during season t

W_{lt}^{rw} — Daily reclaimed water production in region l during season t

W_{lt}^{sw} — Daily wastewater amount discharged to the sea in region l during season t

W_{lt}^{ww} — Daily treated wastewater production within region l during season t

Integer variables

X_{ltm}^{dw} — Number of the desalination plants whose daily production in region l is within interval m during season t

Fig. 3 gives the flow directions in desalination, wastewater treatment and reclamation plants. In the non-potable water system, wastewater is firstly collected for primary and secondary treatments; then the part of the treated wastewater goes for further treatment (at an extra cost), while the rest is disposed to the sea. Reclaimed water is used for non-potable applications. Desalinated seawater, (produced at the desalination plants) is used for all potable applications. The above two systems are integrated by the flows Q_{klt}^{dwnp} (Fig. 2), which is the flow of desalinated water for non-potable use.

In region l, the volume of desalinated water plus all incoming potable water flows (from other regions) should be equal to the potable demands plus all outgoing desalinated water flows (including flows for potable and for non-potable uses):

$$\sum_{k\in SO_l^{dw}} Q_{klt}^{dwp} + P_{lt}^{dw} = \sum_{k\in SI_l^{dw}} Q_{lkt}^{dwp} + \sum_{k\in SI_l^{dw}} Q_{lkt}^{dwnp} + D_{lt}^{p}, \quad \forall l\in L, t\in t \tag{2}$$

In region l, the wastewater production plus all incoming wastewater should be equal to the summation of the outgoing wastewater and the wastewater treated in the wastewater treatment plant in region l:

$$\sum_{k\in SO_l^{ww}} Q_{klt}^{ww} + S_{lt}^{ww} = \sum_{k\in SI_l^{ww}} Q_{lkt}^{ww} + W_{lt}^{ww}, \quad \forall l\in L, t\in T \tag{3}$$

The treated wastewater is the summation of the reclaimed water and the disposed wastewater:

$$W_{lt}^{ww} = W_{lt}^{rw} + W_{lt}^{sw}, \quad \forall l\in L, t\in T \tag{4}$$

In region l, the reclaimed water production plus the incoming reclaimed water and desalinated seawater which is used for non-potable applications is the summation of the outgoing reclaimed water, and the water utilised in region l for non-potable applications:

$$\sum_{k\in SO_l^{rw}} Q_{klt}^{rw} + \sum_{k\in SO_l^{dw}} Q_{klt}^{dwnp} + W_{lt}^{rw} = \sum_{k\in SI_l^{rw}} Q_{lkt}^{rw} + D_{lt}^{np}, \quad \forall l\in L, t\in T \tag{5}$$

The cost of desalinated waters is a piecewise function whose value depends on the capacity of the plant, which has been divided into 3 intervals (Table 3). If X_{ltm}^{dw} plants have their capacities in interval m for in region l, the daily production amount of these plants should be limited as follows:

$$\theta_m^L \cdot X_{ltm}^{dw} \le \tilde{P}_{ltm}^{dw} \le \theta_m^U \cdot X_{ltm}^{dw}, \quad \forall l\in L, t\in T, m\in M \tag{6}$$

The total production is the summation of the productions in all intervals:

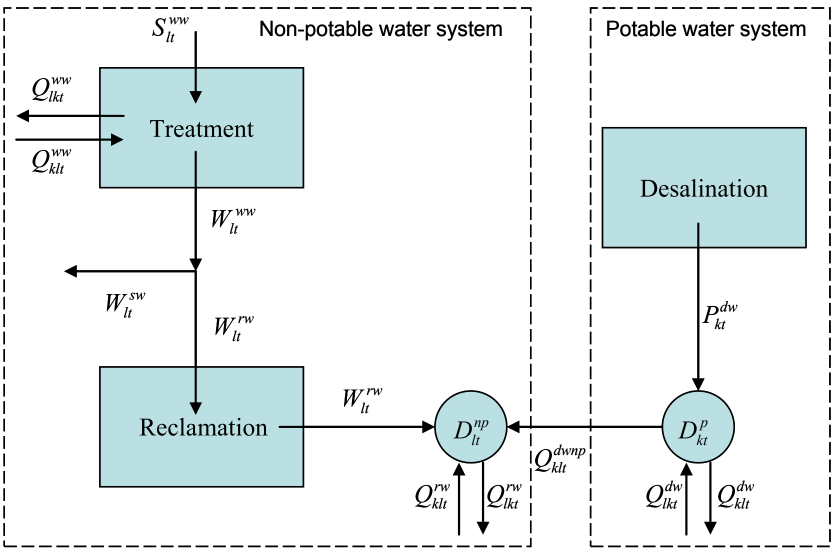

Fig. 3. Schematic graph of wastewater treatment, water reclamation and desalinated seawater production and distribution.

$$P_{lt}^{dw} = \sum_{m\in M} \tilde{P}_{ltm}^{dw}, \quad \forall l \in L, t \in T \tag{7}$$

In region l, the total number of desalination plants should be limited by the maximum allowable number.

$$\sum_{m\in M} X_{ltm}^{dw} \le N_l^{dw}, \quad \forall l \in L, t \in T \tag{8}$$

The productions of treated wastewater and reclaimed water can be formulated using similar constraints as Eqs. (6)–(8). In summary, the above proposed mathematical model is a mixed integer linear programming (MILP) model with Eq. (1) as the objective function.

4. Results and discussion

In this case study, for each type of plant, we allow at most 4 plants can be installed in each region. The model has been implemented in GAMS 22.8 [15], using the CPLEX MILP solver for the optimal solution on a Pentium 4 3.40 GHz, 1.00 GB RAM machine. The optimal solution gives an annualised total cost of US$3299841 (see Table 6 for its breakdown).

Fig. 4 shows the optimal allocations of the plants and the main pipeline network on the island. Based on the optimal solution, there is at most one plant of each type in every region. Thus, the optimal solution indicates that sea water desalination plants are allocated to regions R2 and R5, wastewater treatment plants are allocated to all regions R1 to R6, while water reclamation plants are allocated in all regions except R3. The last is in agreement with the study by Gikas and Tchobanoglous [16], which suggested that the beneficial location of water reclamation and reuse is close to wastewater production sources. In the optimal pipelines network, R1 and R6, R2 and R3, R3 and R4, R4 and R5, R5 and R6 are connected by desalinated water pipeline. Wastewater pipeline is between R1 and R6. Reclaimed water pipelines are between R2 and R3, R3 and R4, respectively. Details for each established link in the optimal solution are shown in Table 7. It should be noted that the directions of the desalinated water flows

Table 6
Breakdown of the optimal annualised total cost

Annualised cost	Value (US$)	Percentage (%)
Total	3299841	100.0
Desalination production	1791784	54.3
Wastewater treatment	321714	9.7
Water reclamation	99726	3.0
Storage	793599	24.0
Pipeline	189493	5.7
Pumping station	32498	1.0
Pumping	71027	2.2

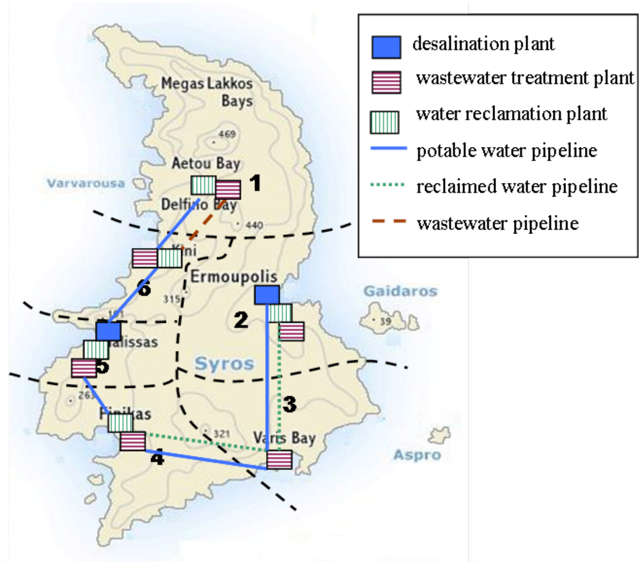

Fig. 4. Optimal plant allocations and pipeline network.

between R3 and R4, as well as flows between R4 and R5, in summer are opposite to those in winter. No wastewater pump station is installed on the link from R1 to R6, as R1 is a higher elevation and there is no "pumping distance" from R1 to R6 (Table 1).

For each plant indicated in Fig. 4, its daily production (summer and winter) is given in Table 8, which shows that the plants in R2 have the larger capacities than other plants.

Fig. 5 illustrates the daily volumes of the potable water in each region, which can be from the local desalination water plant (dw prod) or from the desalinated water flow (dw flow) from other regions. Detailed sources and daily volumes of the potable water flows in each region are given (bold numbers indicates desalinated water productions) in Table 9.

As we mentioned above, the non-potable water originates either from reclaimed water or from desalinated water. In Fig. 6, the non-potable water demand at each region can be satisfied by local reclaimed water production (rw prod), local desalinated water production (dw prod), and reclaimed water flows (rw flow) and desalinated water flows (dw flow) from other regions. The detailed sources and flows for the non-potable water demand in each region during summer and winter are presented in Tables 10 and 11, respectively (bold numbers indicate the reclaimed water productions). The integration between the two systems (Q_{klt}^{dwnp} in Fig. 3) occurs in R1, R4 and R5 in summer and in R5 and R6 in winter (indicated in italic in Tables 10 and 11). 400 m^3/d of desalinated water is used for non-potable applications during summer, while 60 m^3/d is used in winter (11.1% and 25% of the total non-potable water demand, respectively).

Fig. 7 shows the daily volumes of the treated wastewa-

Table 7
Details of optimal solution for each established link

Link	Water type	Pipe diameter (in)	Flow rate (m^3/d)	Direction	Pump type (m^3/d)	Pump No. (including stand by)	Proportion of operation time	
							Summer	Winter
1---6	dw	4	560.4	6→1	720	2	0.45	0.09
2---3	dw	6	1260.9	2→3	2400	2	0	0.96
3---4	dw	6	1260.9	3→4	2400	2	0	0.76
				4→3	2400	2	0.40	0
4---5	dw	6	1260.9	4→5	2400	2	0	0.48
				5→4	2400	2	0.93	0
5---6	dw	6	1260.9	5→6	2400	2	0.60	0.30
2---3	rw	6	1260.9	2→3	2400	2	0.92	0.06
3---4	rw	4	560.4	3→4	720	2	1	0.05
1---6	ww	2.5	273.6	1→6	none	0	0	0.18

dw: desalinated water, rw: reclaimed water, ww: wastewater

Table 8
Daily volumes processed by each plant (m^3/d)

	Regions (summer/winter)					
	R1	R2	R3	R4	R5	R6
Desalination plant		4000/4010			2700/0	
Treatment plant	150/0	3700/2600	200/100	300/150	300/150	450/300
Reclamation plant	150/0	2060/180		300/0	300/0	380/0

Table 9
Sources and flows for potable water (m^3/d)

	Destination regions (summer/winter)					
From	R1	R2	R3	R4	R5	R6
R1						
R2		**4000/4010**	0/1210			
R3				0/960		
R4			500/0		0/610	
R5				1170/0	**2700/0**	750/350
R6	250/50					
Demand	150/50	4000/2800	500/250	650/350	500/200	500/300

ter, which is disposed, and the daily volumes of reclaimed water in the wastewater treatment and reclamation plants in each region.

Finally, we calculated the optimal solution assuming 25% increase in potable and non-potable water demands, and thus in wastewater productions, to account for increased future demands. The relative values may calculated by multiplying the values in Table 2 by 1.25. The optimal solution of the new scenario gives an objective value of US$4062159, whose breakdown is given in Table 12. The location of desalinated and reclaimed water and wastewater treatment plants and conveyance infrastructure, for the last case, is shown in Fig. 8.

In the optimal solution for the last case, the optimal

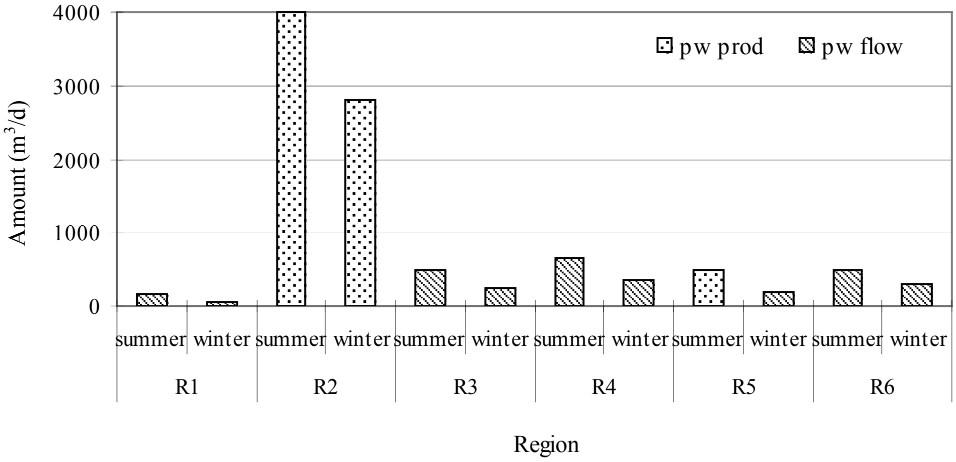

Fig. 5. Daily volumes of potable water supply in each region. (dw prod: desalinated water used for potable applications and produced in the region, dw flow: desalinated water used for potable applications and conveyed from other regions).

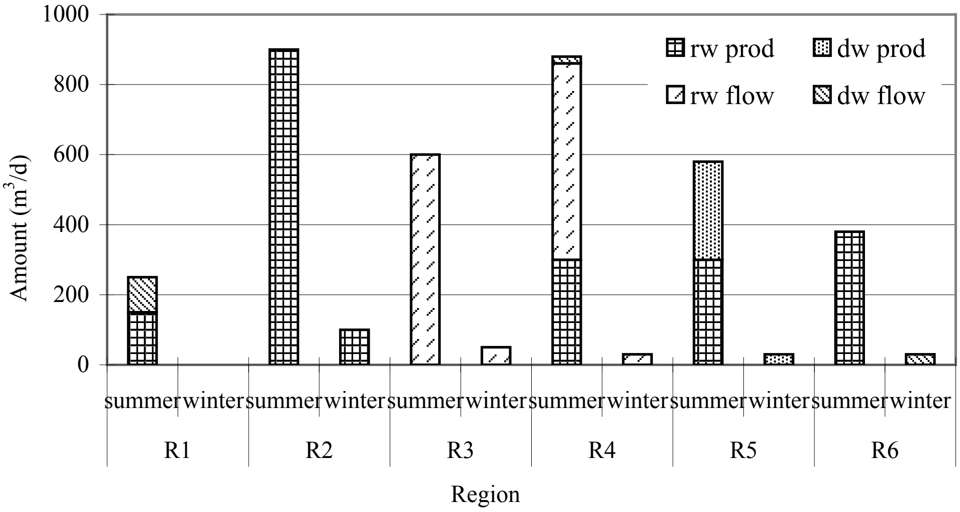

Fig. 6. Daily volumes of non-potable water supply in each region. (rw prod: reclaimed water produced in region, dw prod: desalinated water used for non-potable applications and produced in region, rw flow: reclaimed water conveyed from other regions, dw: desalinated water used for non-potable applications and conveyed from other regions).

Table 10
Sources and flows of non-potable water in summer (m^3/d)

	Destination regions (desalinated water/reclaimed water)											
	R1		R2		R3		R4		R5		R6	
From	dw	rw	dw	rw	dw	rw	dw	rw	dw	Rw	dw	rw
R1		**150**										
R2				**2060**		1160						
R3								560				
R4								**300**				
R5							*20*		*280*	**300**		
R6	*100*											**380**
Demand	250		900		600		880		580		380	

Table 11
Sources and flows of non-potable water in winter (m^3/d)

	Destination regions (desalinated water/reclaimed water)											
	R1		R2		R3		R4		R5		R6	
From	dw	rw	dw	rw	dw	rw	dw	rw	dw	Rw	dw	rw
R1												
R2				**180**		80						
R3								30				
R4												
R5									*30*		*30*	
R6												
Demand	0		100		50		30		30		30	

desalinated water production in region R2 exceeds the maximum capacity for one plant (5000 m^3/d), so two desalination plants are installed in region R2, while there is one desalination plant in each of regions R3 and R5. There are also one wastewater treatment plant and one reclamation plant in each region. It should be noted that water reclamation occurs in R3 as well. The pipeline network is the same as in the original scenario (with no demand increase). Table 13 gives the details of each established link for the last case.

All things considered, it can be concluded that optimisation techniques is a powerful tool for the optimal management of non-conventional water resources. As with any computational technique, the validity of the outcome depends not only on the optimisation algorithm used, but also on the accuracy of the data. In exceptional cases, when data are not readily available, pilot studies may be required to estimate the values of the feeding parameters to the model [17].

Table 12
Breakdown of the optimal annualised total cost for water needs increased by 25%

Annualised cost	Value (US$)	Percentage (%)
Total	4062159	100.0
Desalination production	2236738	55.1
Wastewater treatment	402143	9.9
Water reclamation	128331	3.2
Storage	991999	24.4
Pipeline	191619	4.7
Pumping station	33943	0.8
Pumping	77387	1.9

Fig. 9 shows that the two desalination plants in R2 (indicated as R2(1) and R2(2)) have the same production in summer, but only one of them operates in winter. The

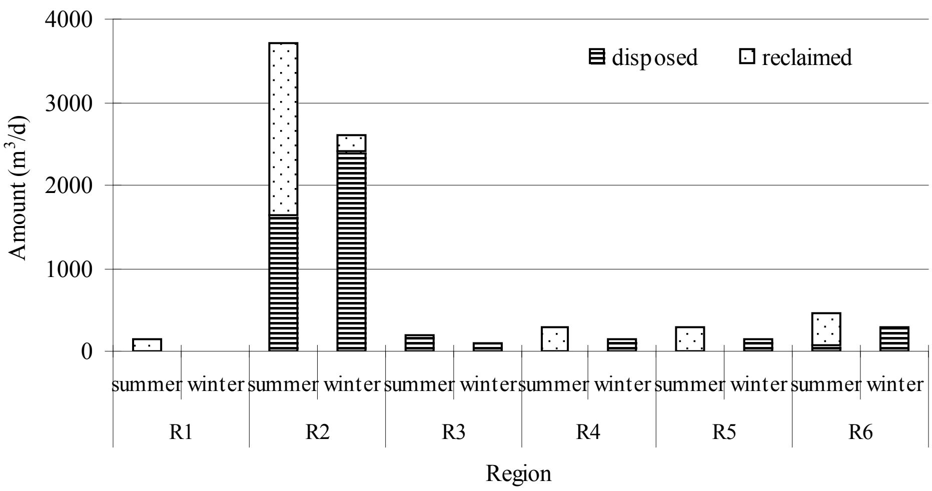

Fig. 7. Daily volumes of disposed treated wastewater and reclaimed water from wastewater by the treatment and reclamation plants.

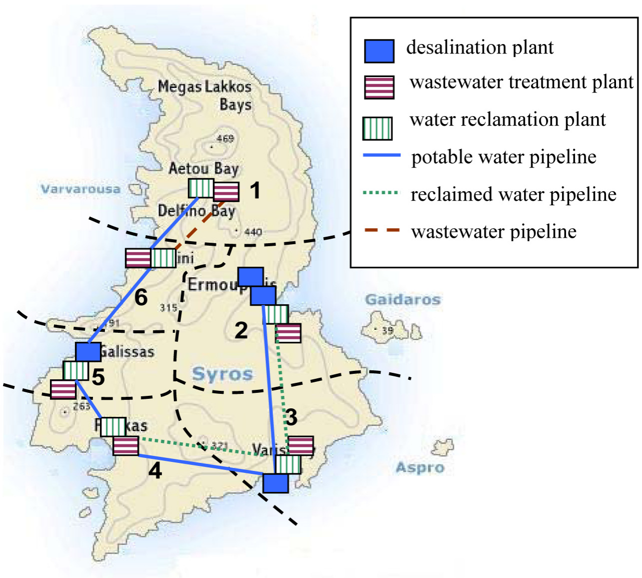

Fig. 8. Optimal plant allocations and pipeline network for water needs increased by 25%.

desalination plants in R3 and R5 only operate in winter and summer, respectively.

5. Conclusions

This paper considers water resources management problem in the island of Syros. An optimisation-based model is developed by minimising the annualised total cost. Based on the estimations about water demand and wastewater production and on the subdivision of Syros island into 6 regions, the model gives the optimal allocations, numbers and capacities of desalination, wastewater treatment and reclamation plants. Also, the water conveyance infrastructure, such as pipeline links/diameters, and number and types of pumps, is optimised. The proposed model can also be applied to other cases if their data is available. In the future work, we may consider more cases and develop the model to predict more accurate solutions.

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Table 13
Solution details for each established link for water needs increased by 25%

Link	Water type	Pipe diameter (in)	Flow rate (m^3/d)	Direction	Pump type (m^3/d)	Pump No. (including standby)	Proportion of operation time	
							Summer	Winter
1---6	dw	4	560.4	6→1	720	2	0.56	0.11
2---3	dw	6	1260.9	2→3	2400	2	0.50	0
				3→2	2400	2	0	0.78
3---4	dw	6	1260.9	3→4	2400	2	0	0.95
4---5	dw	6	1260.9	4→5	2400	2	0	0.61
				5→4	2400	2	0.64	0
5---6	dw	6	1260.9	5→6	2400	2	0.74	0.38
2---3	rw	6	1260.9	2→3	2400	2	1	0
3---4	rw	6	1260.9	3→4	2400	2	0.58	0.03
1---6	ww	2.5	273.6	1→6	none	0	0	0.23

dw: desalinated water, rw: reclaimed water, ww: wastewater

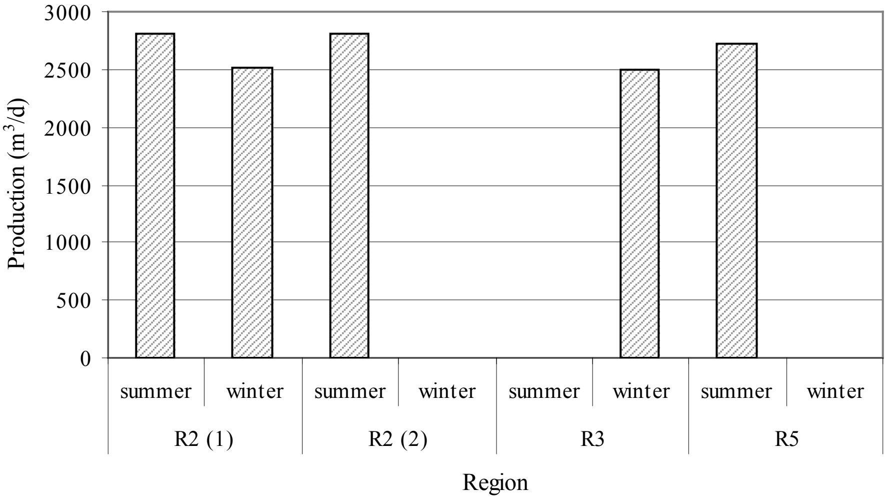

Fig. 9. Daily productions of desalinated water by each plant, for water needs increased by 25%.

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