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Water Resources Status Including Wastewater Treatment and Reuse in Greece
Related Problems and Prospectives

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Abstract: *This paper presents an overview of regional water resources in Greece including water availability, water uses, wastewater reclamation, and reuse trends. Water demand has increased tremendously in recent decades. Despite adequate precipitation, several regions are under water stress due to temporal and regional variations of precipitation, the high rate of evapotranspiration and the high cost of transporting water over the mountainous terrain. To address the problem of water stress, integration of reclaimed wastewater into water resources management is proposed. Data about the current situation of municipal wastewater treatment and reuse options are presented, and regional and temporal trends for wastewater reclamation and reuse are summarized. It is revealed that by proper management and reuse of the effluent from existing municipal wastewater treatment plants, water availability can be increased by 3.2 percent.*

Keywords: *Effluent disposal sites, water resources, water availability, wastewater treatment, wastewater reuse.*

Introduction

Agricultural and landscape irrigation with domestic wastewater has been practiced in many parts of the world for centuries. One of the salient characteristics of Minoan civilization was the architectural and hydraulic function of its stormwater and sewerage systems in its palaces and cities. In the entire structures of most Minoan palaces and cities, nothing is more remarkable than the elaborate sewerage system, while indications for utilization of wastewater for agricultural irrigation extend back to *ca.* 3000–1100 B.C. (Angelakis and Spyridakis, 1996). Although irrigation with sewage effluents is, in itself, an effective way of wastewater treatment (such as in slow-rate land treatment), some degree of treatment must be achieved before the sewage can be used for agricultural or landscape irrigation. This level of pre-application treatment should be practiced for the protection of public health, the prevention of nuisance conditions during storage and application, and the prevention of damage to the crops and soils (Asano, 1998).

Greece is characterized by a severe water imbalance particularly in the summer months, due to low precipitation and, at the same time, increased demands for irrigation and water use due to tourism. The climate of Greece is sub-humid Mediterranean with humid and relatively cold winters and dry and warm summers with an average rainfall of 870 mm/year. Annual rainfall ranges from 300 to 500 mm in the southeast of Greece and from 800 to 1,200 mm in the north-western plains of the mainland, while in some mountainous areas it may be above 2,000 mm. Such great climatological differences are due to the complex vertical and horizontal distribution of the mountains and the great number of islands.

Despite high precipitation (of about 600 mm in the plains and more than 2,000 mm in the mountains), water consumption constitutes a relatively small portion of water availability due to unequal temporal and regional distribution and high evapotranspiration rates. About 45 percent of the total precipitation occurs during the period from December to January. It is estimated that about 65 percent of the annual precipitation occurring in the plains is returned by evapotranspiration, 10 percent returns as surface runoff to the sea, and only 25 percent represents groundwater recharge. In addition, transport of water from water-rich areas to where it is needed cannot be practiced, due to both environmental reasons and the high cost of transporting it across the mountainous terrain. An alternative water resource to be considered is treated effluents from municipal wastewater treatment plants (Angelakis and Diamadopoulos, 1996).

In this paper it is presented the current status of the water resources in Greece, in terms of water availability and use, and evaluated the possibility of treated wastewater reuse for irrigation. Also, cases of wastewater reclamation and reuse are presented and the potential for increase of irrigated area is estimated.

Water Resources Management, Availability, and Water Demand

Although precise estimates of the available water resources in Greece have not been made, most authorities agree that water consumption and use constitute only a small percentage, less than 10 and 15 percent of the annual precipitation and water potential, respectively (Table 1). The total annual precipitation is estimated to be 115,375xMm³ and the total water potential is estimated to be 69,000xMm³ (including water transported from countries to the north). By the beginning of the 1990s, the total water consumption was estimated at 5,500xMm³/year, while by the end of the decade it increased by about 30 percent. It is estimated that water consumption in Greece increases by more than 3 percent annually.

The major water use in Greece is irrigation (17 to 95 percent of total consumption within regions) while domestic use ranges among regions from 3 to 66 percent and industrial use from 0.2 to 16.0 percent. The increased demand for water, either for urban or agricultural use, cannot always be met despite adequate precipitation. Water imbalance is often experienced, especially in the coastal and south-eastern regions, due to temporal and spatial variations of the precipitation, the increased water demand during the summer months, and the difficulty of transporting water due to the mountainous terrain. However, on average, there is a relatively high per capita water availability (i.e., around 5,800 m³/inhabitat/year) Although this is lower than most European countries, it is much higher than that of other Mediterranean regions. For instance, there are regions in Spain (Balearic islands) with a per capita availability of less than 500 m³/year. (Marecos do Monte et al., 1996). In these Mediterranean regions wastewater reclamation and reuse may constitute an appropriate solution.

Greece's agriculture has been improved substantially since 1980 and additional agricultural development mainly depends on water availability. The demand for irrigation water is high, since it is estimated that the mean annual increase in agricultural water use is between 1.0 and 1.5 percent, while at the same time only 36 percent of the available agricultural land was irrigated in 1997 in Crete (Chartzoulakis et al., 1997). On the other hand, there are major losses (seepage, evaporation, leakage, etc.) from water delivered to the agricultural sites for irrigation and the municipal sites for domestic use. In some cases, these losses are estimated to be as much as 45 percent.

An alternative plan for water resources management should include the reclaimed wastewater originating from the wastewater treatment plant effluents. This plan may provide sufficient water for irrigation, while at the same time the pollution loads entering the sea or inland waters will be reduced (Angelakis and Diamadopoulos, 1995).

Wastewater Treatment Status

Greece, with an estimated population of 10.6 million, must comply with the EU 271/91 directive on urban wastewater treatment (EU, 1991). Thus, today 270 Municipal Wastewater Treatment Plants (MWTPs) can serve about 60 percent of the country's permanent population (Figure 1). For the remaining 26 percent, it is estimated that 2,000 MWTPs serving more than 500 population equivalent (P.E.)

Table 1. Available Water Resources and Water Uses by Water Region in Greece

Water Region	Area (km^2)	Precipitation (Mm^3/year)	Water Potential (Mm^3/year)			Water Use (Mm^3/year)				Consumption Index (%)
			Surface	Ground	Total	Agricultural	Domestic	Industrial	Total	
1. West Peloponnese	7,301	8,031	3,050	700	3,750	560.0	23	22.0	605.0	16.1
2. North Peloponnese	7,310	6,404	2,650	900	3,550	653.5	40	68.0	761.5	21.5
3. East Peloponnese	8,477	5,811	1,000	950	1,950	780.0	20	25.0	825.0	42.3
4. West Central Greece	10,199	13,592	9,750	850	10,600	260.0	21	0.5	281.5	2.7
5. Epirus	10,026	17,046	8,500	250	8,750	230.0	31	4.0	265.0	3.0
6. Attiki	3,207	1,642	200	200	400	70.0	270	65.0	405.0	101.3
7. Central Greece and Evia	12,341	9,516	1,900	1,050	2,950	380.0	36	5.5	421.5	14.3
8. Thessaly	13,377	10,426	3,250	1,350	4,600	1,060.0	65	46.0	1,171.0	25.5
9. West Macedonia	13,440	10,599	4,100	850	4,950	582.0	48	30.0	660.0	13.3
10. Central Macedonia	10,389	6,596	6,900	700	7,600	477.0	75	20.0	572.0	7.5
11. East Macedonia	7,280	4,422	4,200	550	4,750	439.0	23	9.5	471.5	9.9
12. Thrace	11,177	8,574	10,900	400	11,300	536.0	35	6.0	577.0	5.1
13. Crete	8,335	7,500	1,300	1,300	2,600	320.0	60	4.0	384.0	14.8
14. Aegean Islands	9,103	5,216	1,000	250	1,250	80.0	37	1.0	118.0	9.4
Total	131,962	115,375	58,700	10,300	69,000	6,427.5	784	306.5	7,518.0	10.9

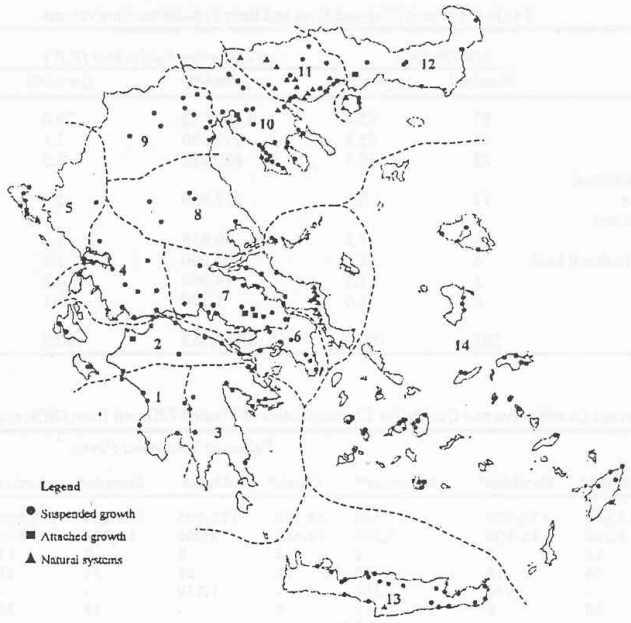

Figure 1. Water regions and MWTPs of Greece according to the treatment system they employ (Tsagarakis, 1999).

will be needed. Fourteen percent of the population is in villages of less than 500 P.E. for which on site sanitation technologies should be used (Tsagarakis, 1999). The following actions present and analyze the wastewater treatment technologies, disposal sites and effluent quality of the MWTPs. Also, the areas under water stress are shortly discussed, and a reuse evaluation in regional level is undertaken.

Wastewater Treatment Technologies

In Greece, specific technologies for municipal wastewater treatment have been developed. Among these systems, 88 percent are activated sludge systems, 10 percent are natural systems, and 2 percent are attached growth systems. Among the activated sludge systems 85 percent are extended aeration systems, 10 percent are conventional systems, and 5 percent are sequencing batch reactors. It is obvious that extended aeration is the dominant system, as it provides additional advantages for Mediterranean climatic conditions. Approximately 44 percent of the activated sludge systems have nitrogen removal, and 15 percent have considered phosphorous removal.

Disposal Sites

At the early stages of wastewater treatment, Greece had not developed its own local knowledge, and therefore, disposal methods were copied from other countries, which had different requirements for water reuse due to local climatic conditions. Sea outfalls were used mostly at MWTPs near the sea for discharging treated effluent. Installations away from the sea usually discharge to both permanent and ephemeral rivers. Other disposal sites are irrigation of agricultural and forested land, lake and land application. The number of MWTPs falling into each category, their total design P.E. and current P.E. (T.P.E.), which reflects the current average flow rate in the hot season are presented in Table 2. Excluded from this evaluation are the plants that have failed, and also natural wastewater systems because the effluent flow rate is very low compared to influent, or even non-existent. Effluent disposal sites in Greece are also described in Tsagarakis et al. (1998).

Effluent Quality

Tsagarakis (1999) has classified the MWTPs in operation according to their performance, taking into account effluent qualitative parameters and the effluent quality requirements. Of existing MWTPs, 42 percent were operating well, 41 percent moderately, and 17 percent poorly. In general, large plants tend to operate well. Qualitative and quantitative values from some large MWTPs of Greece are presented in Table 3.

Table 2. Effluent Disposal Sites and their Population Equivalents

Disposal Site	*MWTPs Sites*		*Population Equivalent (P.E.)*		*Current P.E.*	
	(number)	*(percent)*	*(number)*	*(percent)*	*(number)*	*(percent)*
Sea	93	45.4	6,409,082	79.0	4,832,100	85.6
Ephemeral River	49	23.8	577,390	7.1	236,300	4.2
Permanent River	22	10.7	689,486	8.5	408,500	7.2
Indirect irrigation of agricultural land with prior dilution	17	8.3	238,950	2.8	51,500	0.9
Irrigation of forested land and fire protection	15	7.3	90,955	1.1	34,800	0.6
Directly irrigation of agricultural land	4	2.0	94,000	1.2	76,000	1.3
Lake	3	1.5	14,000	0.2	3,000	0.1
Land	2	1.0	3,700	0.1	500	0.1
Total	205	100.0	8,117,563	100.0	5,642,700	100.0

Table 3. Average Quantitative and Qualitative Characteristics of Treated Effluent from Different MTWPs in Greece

Parameters	*Values at Treatment Plants*								
	Agios Nikolaos[a]	*Heraklion*[a]	*Rethimnon*[a,b]	*Chania*[b]	*Rhodes*	*Ioannina*[a]	*Larissa*	*Lamia*[a,b]	*Kavala*[b]
Current P.E.	14,000	110,000	57,500	40,500	120,000	110,000	113,000	50,000	70,000
Q_e (m^3/d)[c]	1,500	15,000	7,500	10,400	8,000	17,089	19,000	7,500	12,000
BOD_5 (mg/l)	16	8	8	4	9	8	11	21	18
COD (mg/l)	54	15	40	29	25	38	28	-	90
TDS (mg/l)	-	950	1,500	-	1,250	-	-	-	-
SS (mg/l)	20	8	13	8	-	13	20	6	23
NTU	-	-	7.5	-	-	-	-	10.0	-
EC (μS/cm)	-	1.55	2.35	-	-	0.95	-	0.80	1.00
pH	7.70	7.65	7.75	7.50	7.60	7.69	7.80	7.90	7.35
TKN (mg/l)	-	20.00	2.50	4.50	-	11.50	-	-	-
NH_4-N (mg/l)	2.10	4.50	0.65	0.40	0.50	9.65	3.00	5.10	1.50
NO_3-N (mg/l)	0.90	6.00	0.65	7.10	3.50	4.66	7.50	2.30	4.00
NO_2-N (mg/l)	-	-	0.15	0.47	-	0.30	-	-	0.65
Total P (mg/l)	-	12.50	5.00	7.90	7.60	4.28	8.00	8.00	4.00
Total K (mg/l)	-	25.00	-	-	-	-	-	-	-
Cl^- (mg/l)	-	-	500	-	800	-	-	-	-
Cu (mg/l)	-	-	-	0.013	-	-	-	-	-
Fe (mg/l)	-	-	-	0.15	-	-	-	-	-
Mn (mg/l)	-	-	-	0.02	-	-	-	-	-
FC (MPN/100 cm^3)	-	0	1,000,000	275	-	0	-	-	-
TC (MPN/100 cm^3)	1,000	15	23,000,000	-	-	25	-	-	-

[a]Average values for 1999; [b] Without disinfection; [c] Q_e: Effluent average daily flow rate.

Wastewater Reclamation and Reuse

Areas Under Water Stress

The main natural reason for causing the above mentioned negative water balance is the large number of small islands in the south-eastern part of the country where the precipitation is reduced, the groundwater tables of mainly carstic aquifers are open to the sea and discharge large quantities of water into the sea as brackish water, and where there is a large ratio of coastal areas to those of inland. At the same time, the structure and orientation of the economy (seasonality of use because of tourism) dexasperate the problem of water demand in these areas.

The majority of small Aegean islands, eastern Crete and particular southeastern coasts are the Greek areas which are affected by those conditions. A number of those areas, due to geological circumstances, the bad quality of water, and the lack of rational administrative policies, are confronted with a permanent negative water balance, whose continuous deterioration causes economic and social problems. Because their solutions appear to be very costly, wastewater reclamation and reuse need to be practiced.

Reuse

An investigation has been carried out to estimate the suitability for reuse of reclaimed water in three main categories of uses: agriculture, forestry and fire protection, and landscape irrigation. An average effluent production of 150 liters/inhabitant/day is used in the calculations. The results are presented in Table 4. It can be concluded that by reusing the effluent of the existing MWTPs water reuse, particularly for irrigation of agricultural land, can be

Table 4. Potential for Effluent Reuse of MWTPs for Various Purposes in m^3

Region	Irrigation of Agricultural Land	Irrigation of Forested Land & Fire Protection	Landscape Irrigation	Total Reuse Potential	Percentage of Saving over Water used in Rural Areas
1. West Peloponnese	1,660,896	278,240	0	605,000,000	0.3%
2. North Peloponnese	19,205,753	3,066,000	2,299,500	761,500,000	3.2%
3. East Peloponnese	9,863,213	3,339,750	0	825,000,000	1.6%
4. West Central Greece	5,674,838	766,500	1,095,000	281,500,000	2.7%
5. Epirus	7,599,300	1,450,875	3,816,075	265,000,000	4.9%
6. Attiki	2,896,275	3,394,500	29,565,000	405,000,000	8.9%
7. Central Greece and Evia	13,561,575	4,380,000	5,639,250	421,500,000	5.6%
8. Thessaly	8,924,250	3,558,750	0	1,171,000,000	1.1%
9. West Macedonia	17,421,450	0	0	660,000,000	2.6%
10. Central Macedonia	17,520,000	5,529,750	4,763,250	572,000,000	4.9%
11. East Macedonia	3,235,725	4,599,000	657,000	471,500,000	1.8%
12. Thrace	13,003,125	1,040,250	328,500	577,000,000	2.5%
13. Crete	16,490,700	4,026,863	0	384,000,000	5.3%
14. Aegean Islands	4,302,803	7,418,625	9,759,461	118,000,000	18.2%
Total	141,359,901	42,849,102	57,923,036	7,518,000,000	3.2%

increased by 242 Mm^3/year or 3.2 percent of the current total use of freshwater. Thus the freshwater that is currently used for irrigation can be saved. This is related to the availability of nearby agricultural areas and assumes that the relevant infrastructure like storage reservoirs and distribution systems will be available.

In Greece, no guidelines or criteria for wastewater reclamation and reuse have yet been adopted. Note that secondary effluent quality criteria are used for discharging purposes with a Health Arrangement Action of 1965 (Ministries of Interior and Public Health, 1965) and are independent of the disposal, reclamation, and reuse effort. Also, no regulation of wastewater reuse exists at European level. The only reference to it is the article 12 of the European Wastewater Directive (91/271/EEC) (EU, 1991) stating: "Treated wastewater shall be reused whenever appropriate." In order to make this statement a reality, common definitions of what is "appropriate" are needed. Thus, the need for establishing wastewater reclamation and reuse standards on both European and national level is obvious (Angelakis et al., 1999). In Greece, a preliminary study for establishing quality criteria is in progress (Angelakis et al., 2000). These criteria are summarized in Table 5.

Cases of Wastewater Reuse

Agricultural Reuse

There are only a few MWTPs where effluent is used for direct irrigation of agricultural land. These include:

- At Levadia, 3,500 m^3/d are used to irrigate cotton. Advanced treatment includes nutrients control (N-P). The irrigation method is closed pipe network.
- At Amfisa, 400 m^3/d are discharged into a 30,000 m^3 reservoir for the irrigation of olive trees.
- At Palecastro, 280 m^3/d are used to irrigate olive trees after loading on a 20 m^3 charge reservoir. The irrigation method is closed pipe network.
- At Ko, an installation of a small number of agricultural and other trees close to the installation is irrigated, but it is in the planning process to irrigate more in the future with the 4,000 m^3/d effluent that can be produced. Advanced treatment includes nutrient control (N-P).
- Effluent from some of the waste stabilization ponds in operation is used for agricultural irrigation by farmers. Local skin infections have been reported when the effluent comes in contact with farmers' hands (this should be expected as some of these systems are not properly designed or maintained).

The Pefkochori, Kolindros, Chaniotis, and Kalithea plants are in the process of changing the initial disposal site to irrigation of agricultural land. In addition plants that serve Perama, Nea Epidavros, Thermisia, Kranidi, Arahova, Nikita, Nea Kalikratia, Nea Potidea, and Thiva are planning to use treated effluent for irrigation of agricultural land.

It should be noted that there are plants that discharge to ephemeral rivers and after infiltration there is pumping through adjacent wells by farmers for irrigation. This is a way of indirect reuse for irrigation.

Forestry and Landscape Reuse

The effluents from four plants are used for the irrigation of forestry and other amenity purposes:

- At Kentarchos (Serifos), 100 m^3/d are used to irrigate trees after applying sand filtration.
- At Agios Konstantinos (Samos), 200 m^3/d are used to irrigate trees (mainly pine) using a sub-surface system.

Table 5. Proposed Minimal Microbiological and Physicochemical Criteria for Treated Wastewater Effluents Reuse in Greece

Wastewater Effluents Reuse[a]	*Quality Criteria*				
	Microbiological		*Physicochemical*		
	Nematodes eggs[b]	*Escherichia coli*	*SS*[d]	*Turbidity*	*Other Criteria*
Urban Use[f]					
a) Residential uses: Private garden watering, toilet flushing, home air conditioning systems, car washing.	<1 egg/10L	0 cfu/100ml.	<10 mg/L	<2 NTU	
b) Urban uses and facilities: Irrigation of areas with free admittance (parks, golf courses, sport fields,...), street cleaning, fire-lighting, fountaings, and other recreation places.	1 egg/L	<10 cfu/100mL	<20 mg/L	<5 NTU	
Agricultural Use[g]					
a) Irrigation of vegetables to be eaten uncooked. Sprinkler-irrigated fruit trees.	<1 egg/L	<10 cfu/100mL	<20 mg/L	<5 NTU	*Legionella pheumophila* 0 cfu/100mL
b) Irrigation of fodder crops for livestock (for milk or meat production)	<1 egg/L	<1,000 cfu/100mL	<35 mg/L	No limit established	*Taenia saginata* and *Taenia solium*
c) Irrigation of crops for: a) canning industry, b) vegetables to be eaten cooked, and c) fruit trees (except sprinkler-irrigated).	<1 egg/L	<1,000 cfu/100mL	<35 mg/L	No limit established	
d) Irrigation of industrial crops, plant nurseries, stored fodder, cereals, and oleaginous seeds.	<1 egg/L	<1,000 cfu/100mL	<35 mg/L	No limit established	
e) Irrigation of wooden areas, industrial wood areas, greenbelts or other areas where the general public is not allowed to enter.	<1 egg/L	<10,000 cfu/100mL	<35 mg/L	No limit established	
Aquaculture[c,g]					
a) Aquiculture (production of vegetal or animal biomass)	<1 egg/L	<1,000 cfu/100mL	<35 mg/L	No limit established	
Industrial Use					
a) Industrial cooling (except for food industry).	No limit established	<10,000 cfu/100mL	<35 mg/L established	No limit 0 cfu/100mL	*Legionella pheumophila*
Environmental Use and Entertainment					
a) Ponds, bodies of water and streams for recreational purposes, where the public is allowed contact (except for bathing purposes).	<1 egg/L	<200 cfu/100mL	<35 mg/L	No limit established	NO_3 <100 mg/L
b) Ponds, water bodies and ornamental streams, where the public is not allowed contact.	No limit established	<100 cfu/100 mL	<35 mg/L	No limit established	NO_3 <100 mg/L
Groundwater Recharge					
a) Groundwater recharge[e,c], surface spreading (through soils)	<1 egg/L	<1,000 cfu/100mL	<35 mg/L	No limit established	Total Nitrogen <50 mg/L
b) Groundwater recharge: direct injection[h]	<1 egg/10L	0 cfu/100mL	<10 mg/L	<2 NTU	Total Nitrogen <15 mg/L

[a] Minimal wastewater treatment level secondary or equivalent.
[b] Intestinal Nematodes (in eggs/L) include the following families: *Strongyloides, Trichostrongylus, Toxocara, Enterobius* and *Capillaria.*
[c] Control of odor is required.
[d] SS: Suspended Solids.
[e] Minimal depth of groundwater required at 5 m.
[f] Above values must be conformed at the 80 percent of the samples per month.
[g] Reclaimed wastewater can be reused for agricultural purposes, except for irrigation plants for human consumption, it is forbidden by the Greek law.
[h] The agricultural use also required additonal criteria for TDS, Cl-, and various minerals, etc.
[i] Control of heavy metals in the source.
[j] Avoidance of using disinfection with Cl-. Also, consider: i) Integrated management of water reesources; ii) seasonal storage, which improves the quality and the availability; iii) irrigation method: the sub-surface irrigation requires inferior quality effluents; and iv) quality supervision in point of the sampling method, the frequency reception and the reliability of analyses.

- At Karistos, 1,450 m³/d are used to irrigate 14,000 trees using nearly all the effluent with a closed pipe network.
- At Ierisos, 1,200 m³/d are discharged into a reservoir before irrigating forested land.
- At Chalkida, the disposal site to sea is being diverted to the surrounding area. In addition, at Serifos, Marpisa, Kini, Karterados, Chora (Samos), Nea Artaki, and Siviri there are plans to irrigate land for forestry and amenity.

Industrial Reuse

There is no industrial reuse of treated effluent apart from some installations that use filtration for treating further effluent that is going to be used in the installation. Industries that are heavy water consumers such as food processing will be increasingly interested in using reclaimed wastewater, particularly in areas under water stress.

Conclusions

Water resources are limited in Greece. The continued increase of potable water demand can only be met through an integrated water management scheme that includes the use of all sources including marginal waters. This study reveals that by proper management and reuse of the effluents from the existing MWTPs, the savings in water used can be increased by 3.2 percent. This percentage will be substantially increased as the number of MWTPs increase. Currently only at a few MWTPs are effluents reused for agriculture and forestry. However, this will increase in the near future due to more appropriate chooices of effluent disposal and the change of some MWTPs from sea or river disposal to irrigation.

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