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Integrated Wastewater Management Reporting at Tourist Areas for Recycling Purposes, Including the Case Study of Hersonissos, Greece

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ABSTRACT / Wastewater treatment facilities in tourist areas, in comparison to other municipal facilities, require specific configurations and additional management actions in order to achieve a reliable and cost-effective treatment. For example, the same facility operates during winter with minimum flows and in summer with peak flows. Moreover, careful effluent management is required to minimize environmental impact and health effects on tourists. In this study, effluent management data, including quantitative and qualitative effluent characteristics, reuse, and economic aspects of the Hersonissos Wastewater Treatment Plant (WTP) in Greece, are discussed. It has been designed to treat both municipal wastewater from the Hersonissos Municipality and septage from the wider area. Analysis of effluent quantitative data showed two flow peaks in the summer period and only one in winter. The WTP was found to provide a reliable level of treatment in terms of biochemical oxygen demand (95.9%), total suspended solids (97.2%), and total nitrogen (87.7%) removal, but increased numbers of fecal coliforms were measured at some peak flow periods, suggesting the need for additional management strategies. Effluent is reused mainly for agricultural irrigation; secondary uses include fire protection and landscape irrigation. Economic analysis showed that for each cubic meter treated, the total annual economic cost for treatment, filtration, and reuse infrastructure was 1.07 €, 0.05 €, and 0.08 €, respectively.

One of the most critical issues in tourist resorts is to ensure adequate water supplies of high quality. Because many resorts are located in areas with arid and semiarid climates, water availability has often been a limiting factor for the development of tourism (Kent and others 2002). Not only do tourists consume more water per capita than local inhabitants (Holden 2000), but the water requirements in such areas also increase as a consequence of the demand for water for landscape irrigation, pool maintenance, and washing. This high demand for water coincides with the driest period of the year, when the water supplies reach their lowest levels. A long-term management plan for water resources is essential to ensure that the quantitative and qualitative water demands needed to maintain tourism development in such areas are met. These plans should give emphasis to the efficient use of existing water supplies as well as to the use of marginal waters, such as treated effluents.

Wastewater recycling for various beneficial uses currently constitutes an increasing practice worldwide, particularly in areas with deficient water resources (Angelakis and others 1999, Anderson 2003, Angelakis and others 2003, Oron 2003). Wastewater reuse has significant advantages, such as protection of the environment and saving of high-quality freshwater resources. However, effluent reuse might also have environmental impacts and health risks. Wastewater reclamation and reuse in tourist areas has some specific characteristics compared to other towns, including large seasonal flow variations, the need for efficient onsite wastewater management, and higher treatment requirements to minimize the potential health risks.

This article focuses on wastewater treatment processes, including effluent quantitative and qualitative

KEY WORDS: Irrigation; Cost; sludge management; wastewater treatment; water management; water recycling

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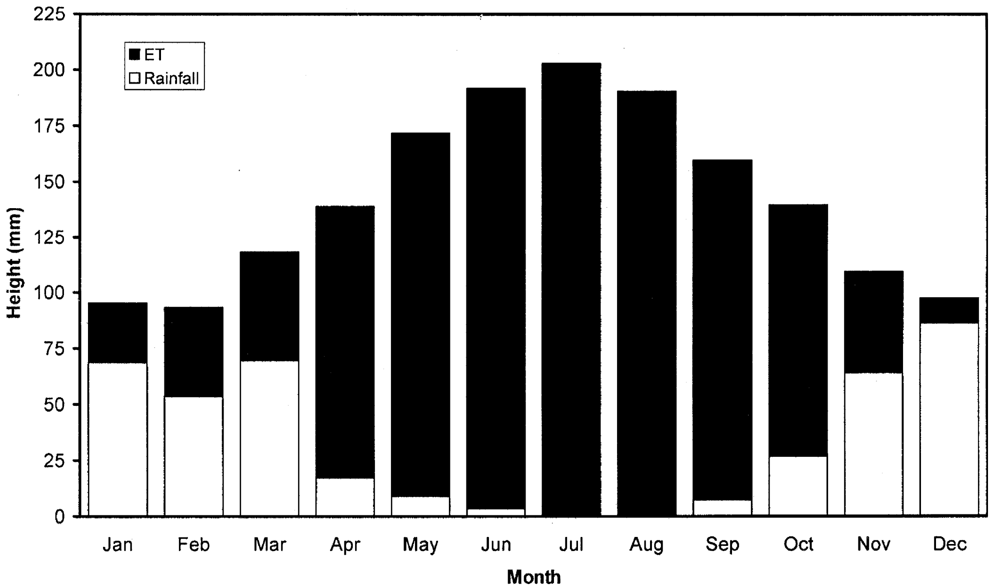

Figure 1. The ET and rainfall values in the Hersonissos area. Each bar represents average values for the period 1990–1999 according to the meteorological station of Iraklio. The ET was calculated by the Branley–Griddle method. (From Doorendos and Pruit, 1977)

analysis, the existing recycling scheme, the resulting benefits, and the treatment cost of the Hersonissos Wastewater Treatment Plant (WTP).

Hersonissos is a well-known Mediterranean resort located on the eastern part of the island of Crete. The Hersonissos WTP has been managed and operated since July 2001 by the Hersonissos Municipal Enterprise for Water Supply and Sewerage. The population served by the WTP shows a high seasonal variation due to tourism, ranging from 10,000 in winter to 60,000 in summer.

Water and Wastewater Management

The water economy for the island of Crete is based mainly on groundwater resources. Although the available water supplies appear adequate to meet water demands, the spatial and temporal variation in their availability, coupled with the lack of proper organization and infrastructure, can lead to serious problems, especially in eastern Crete. Agriculture is the major water user, consuming approximately 86.7% of the available water (446 mm); the domestic and the industrial sectors consume the remaining 13.3% (Region of Crete 2002). Over the past 20 years, however, a significant change has been observed in the pattern of water consumption by different users, with urban and tourism activities consuming more and more water, leading to increased competition between these sectors and agriculture.

The transport of water from regions with increased water availability (i.e., western Crete) exhibits severe technical, economical, and social limitations. Thus, the only viable solution to overcome water scarcity in these areas and maintain development is the adoption of integrated water resources management plans that include the use of recycled water. Such plans would not only provide additional water for various beneficial uses, but also significantly contribute to the protection of public health, and the prevention of coastal pollution.

Municipal wastewater treatment coverage in Crete has increased during the past two decades. In 1994, there were 9 WTPs in operation. This figure had increased to 13 by 1998 (Tsagarakis 1999). The number of WTPs in operation today is 25. By 2006, this number is expected to have increased to 46. It is estimated that almost all Cretan municipalities with a population equivalent (p.e.) of 2000 or more will be connected to the WTP, providing at least secondary treatment by 2005 (Tsagarakis and others 2004).

Hersonissos can be classified as a semiarid region. As shown in Figure 1, the potential evapotranspiration (ET) exceeds rainfall for the entire year (data are from the decade 1990–1999). More specifically, 85% of the rainfall occurs within 5 months (November to March), whereas almost no rainfall occurs from May to October, when water requirements reach their maximum values.

Because there are no surface water bodies in the wider area of Hersonissos, water demands are met from groundwater sources. Due to increased water demands during the summer period, a significant drop of approximately 10 m (from 27 m to 17 m) in the aquifer water table occurs as shown in Figure 2 (Papamastorakis, unpublished data).

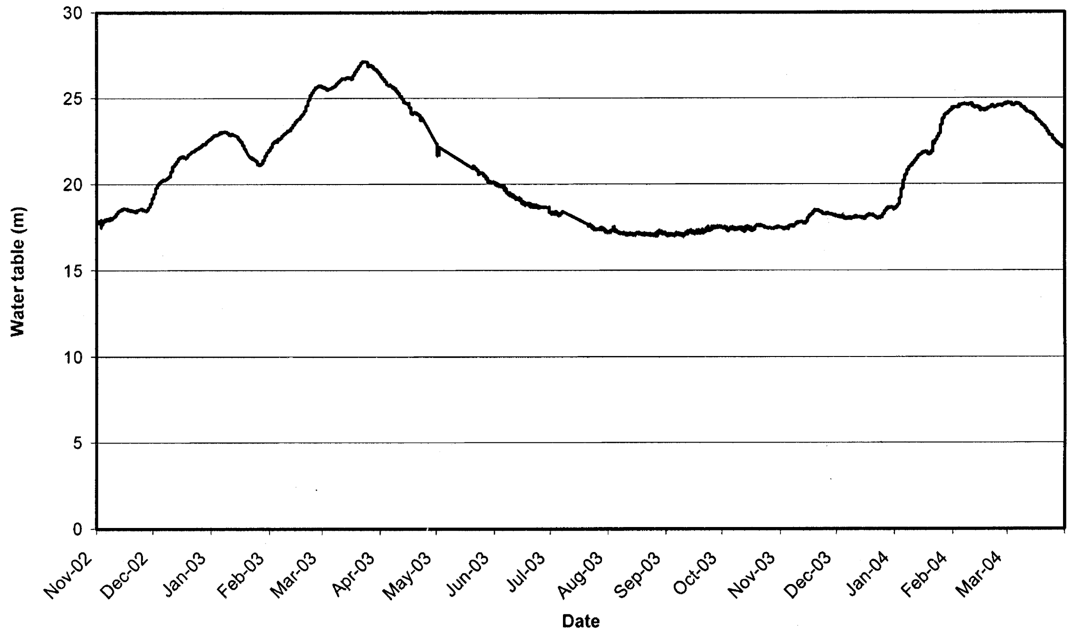

Figure 2. Variation of the water table (7-day moving average) in the aquifer, as reported from a representative well in Malia area (5 Km east of Hersonissos).

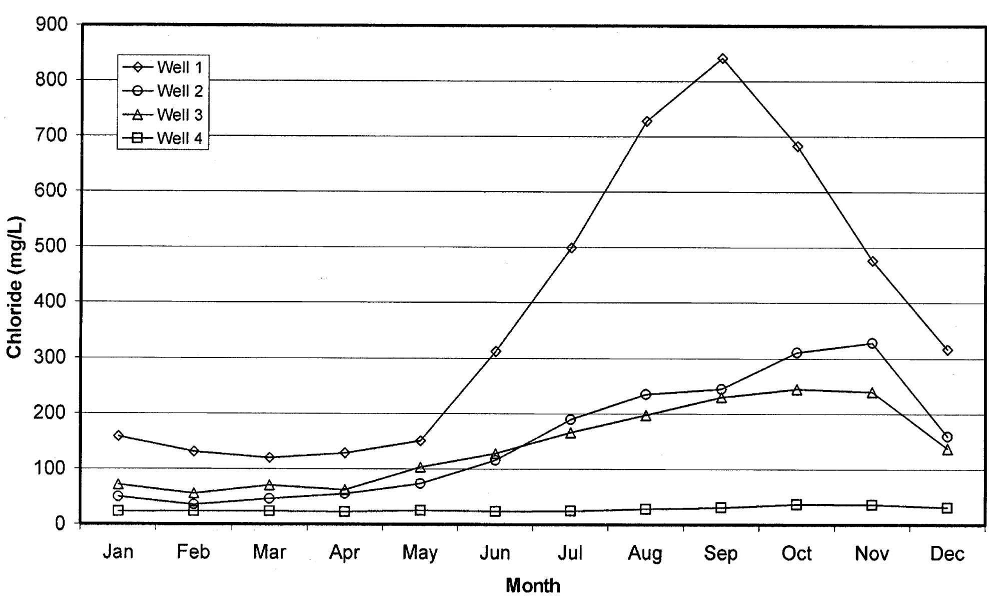

Figure 3. Average variation in chloride concentration during the year at four wells differing in the distance from the sea (well 1 closest; well 4 furthest). Each point represents the averaged value for 6 years.

This drop, in conjunction with the calcareous beds, favors sea intrusion, resulting in significant increases in chloride concentration and electrical conductivity (EC) of groundwater, as shown in Figures 3 and 4, respectively (Koumakis, unpublished data). Observed values might be detrimental for plant performance. This increase is a function of the distance from the sea, with the most severe impact on groundwater quality occurring close to the sea (well 1), less impact further from the sea (wells 2 and 3) and no effect observed at all at wells located far from the sea (well 4).

Wastewater Treatment

This section deals with the WTP of Hersonissos, focusing mainly on the design and operation parameters.

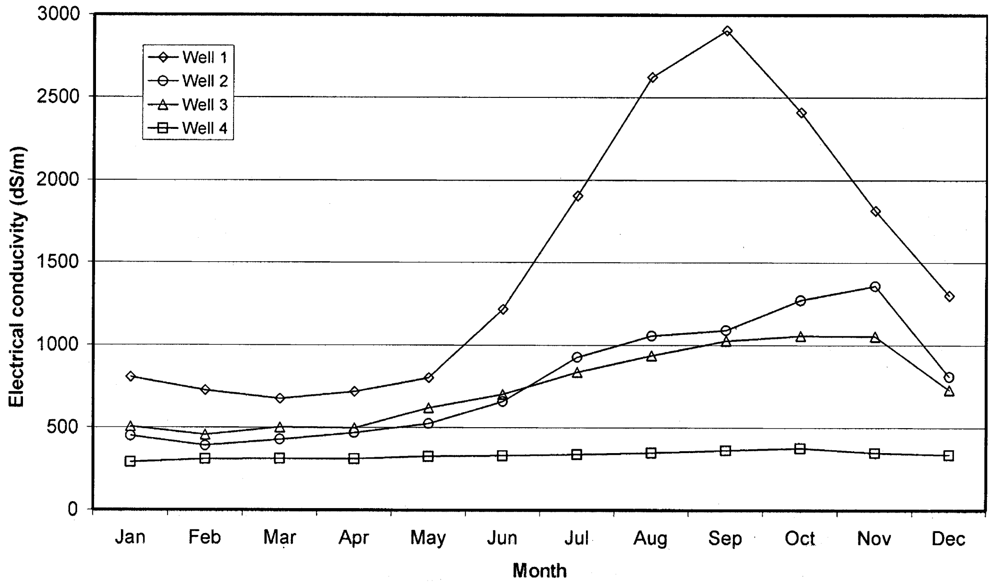

Figure 4. Average variation in EC during the year at four wells differing in the distance from the sea.

Table 1. Design parameters of the Hersonissos WTP

	First phase		Second phase	
Parameter	Winter	Summer	Winter	Summer
Equivalent population	9,000	40,000	12,000	60,000
Average daily flow (m^3/day)	1,800	8,000	2,400	12,000
Peak flow (m^3/h)	450	750	515	1,125
BOD_5 inlet (kg/day)	540	2,400	720	3,600

Design Parameters

A characteristic feature of tourist resorts is large wastewater seasonal flow variations. Greater than 20 times flow variation from winter to summer in various tourist areas of Greece has been reported (Tsagarakis 1999). This variation necessitates the design of WTPs along parallel lines: a low flow line and a second larger flow line. The first line operates during the winter, the second during the change of the seasons, and both during peak flows. Alternatively, there might be two or three parallel lines of the same capacity. The operation mode might also change from a conventional system in summer to an extended aeration system in winter. In addition, in cases where the permanent population and/or the number of tourists is expected to grow, an expansion of the treatment plant is predicted.

Two parallel lines have been established at the Hersonissos WTP. The WTP has been designed to operate within a wide range of hydraulic and organic loads in order to overcome the seasonal variations in wastewater flow. Design parameters concerning the two design phases and seasons (the first phase until the year 2015 and the second phase until the year 2035) are presented in Table 1.

The Hersonissos WTP is designed as a conventional activated sludge system and operates at 0.20–0.40 F/M (ratio food/microorganism) and 3500–5000 mg/L mixed liquid suspended solids (MLSS) (mean: 4400). During the winter, however, the plant operates as an extended aeration system at 0.04–0.15 F/M and 4500–7500 mg/L MLSS (mean: 6500).

The recirculation rate ($r = Q_R/Q$) varies from 0.30 to 0.60 in summer and from 0.70 to 1.40 in winter. The sludge retention time (SRT) fluctuates from 7 to 14 days in the summer and from 20 to 30 days in the winter. The plant's wastewater treatment operational flowchart is shown in Figure 5.

Operational Parameters

Wastewater treatment plants are designed to operate under certain modes; different operational functions might apply in individual cases. The Hersonissos WTP receives 150–1500 m^3/day of septage. In the aerated sand–grease removal unit, aeration is

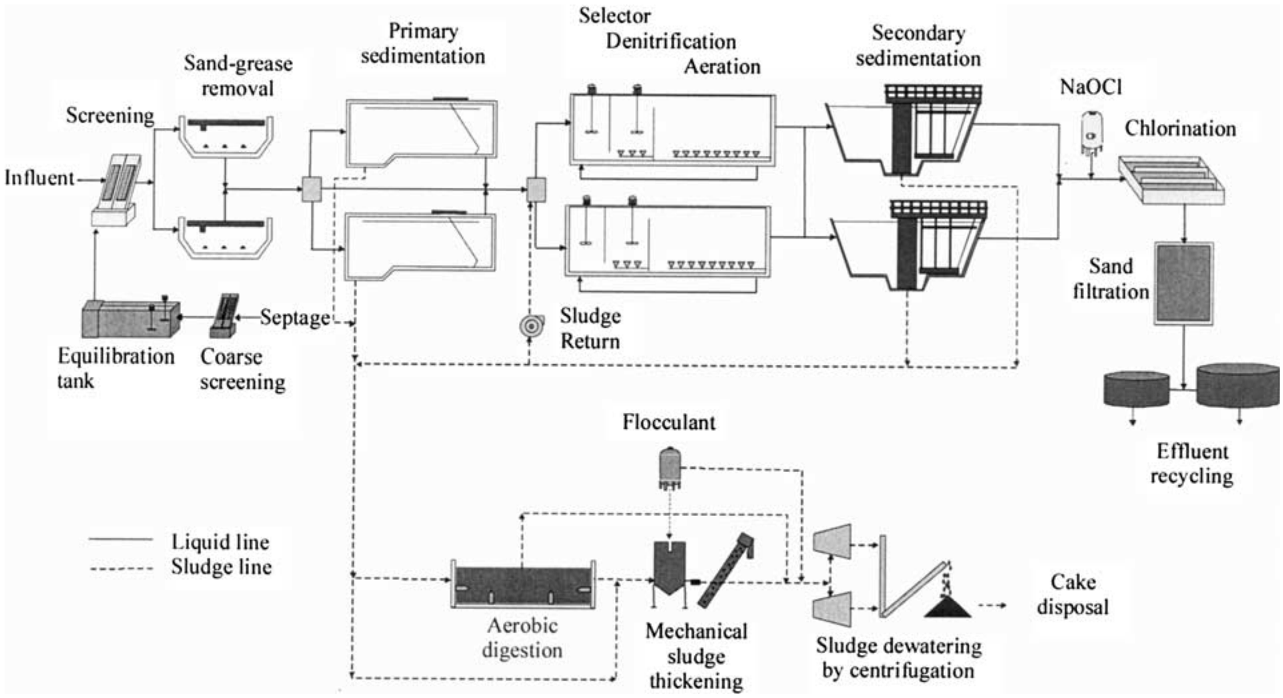

Figure 5. Hersonissos WTP operational flowchart.

obtained through 110 membrane disk diffusers/tank (270 m^3 air/h/tank). The primary sedimentation does not operate continuously, as it has been shown to be cost-effective to bypass it because of the low loading rates during the winter. A selector is used to inhibit excessive growth of filamentous organisms and to eliminate sludge bulking problems. Recirculation rates of mixed liquids varies from 2.8 to 4.3 during the winter and from 5.2 to 9.2 during the summer. The minimum retention time of the chlorination process is 60 min with a disinfectant dose of 3 mg/L. The retention time fluctuates from 7.6 to 24.4 h in the winter and from 2.16 to 7.20 h in the summer. In the Hersonissos WTP, considerable attention has been given to the elimination of odors. This is achieved by an odor-removal unit for (1) septage equilibration lines, (2) screen sand–grease removal building, and (3) sludge dewatering building, with a total capacity air removal of 10,000 m^3/h.

Wastewater Quality and Quantity Data Analysis

The quality and quantity data regarding the Hersonissos WTP are presented in this section. These data are of value in optimizing the operation efficiency of WTPs, achieving a cost-effective operation, and in drawing conclusions for the design, construction, and operation of WTPs in areas with similar characteristics.

Wastewater Quantity

The temporal fluctuation in sewerage flow rates in the Hersonissos WTP from July 2002 to June 2003 is shown in Figure 6. The lowest flow rates were observed in November (300 m^3/day) and the highest ones (4000 m^3/day) in July.

A significant variation in sewerage flow rates was also observed during the day (Figure 6). Representative daily flow rate fluctuations for the winter (December) and summer (August) are shown in Figure 7. Peak flow hours in the summer period occur between 09.00 and 14.00 and between 18.00 and 22.00, but only the first peak can be clearly observed in winter. This seasonal differentiation is ascribed to the lack of tourist activities during the winter.

Wastewater Quality

The composition of sewerage wastewater is within the typical range reported for municipal wastewaters in Greece (Tsagarakis and others 2001). The significant amounts of septic wastewater that are discharged in the WTP (800–1000 m^3/day during summer), however, dramatically change the qualitative characteristics of the WTP influent. It is estimated that septic wastewater accounts for up to 22% of the total flow rate, 46% of the biochemical oxygen demand (BOD_5), 64% of the suspended solids (SS), 45% of the total nitrogen (TN),

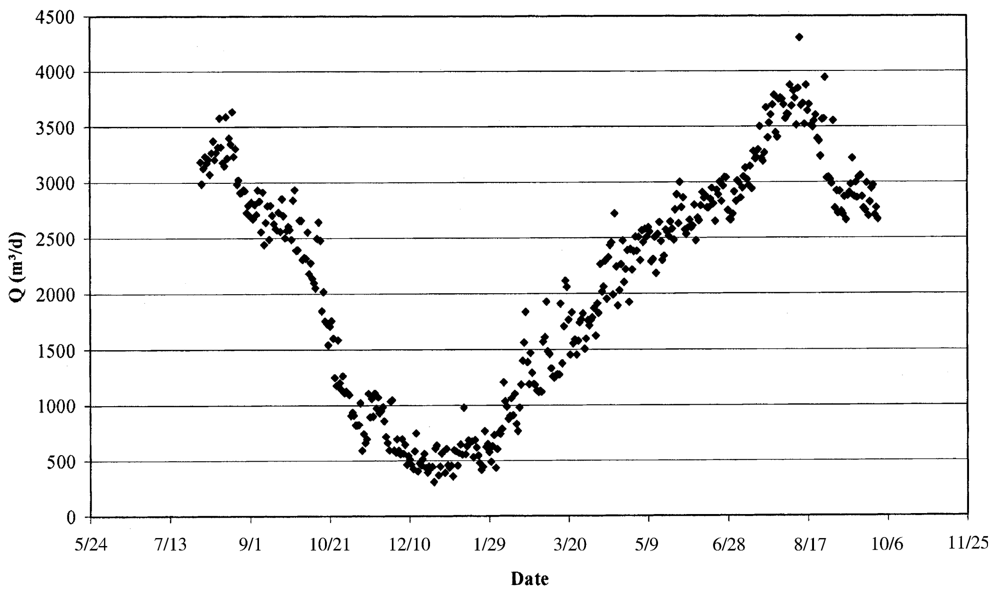

Figure 6. Flow rate variations for years 2002 and 2003.

and 54% of the total phosphorus (TP) loads (Table 2). The pH values of WTP influent were not affected by septic wastewater (Table 2). There is no need, therefore, to adjust the pH by adding chemical agents.

As shown in Table 3, the average removal of BOD_5, TN, and TSS reached 95.86%, 87.65%, and 97.23%, respectively. The sand filtration unit, which is in operation only during the summer period (April–October), resulted in a further 56% removal of SS on average. Although the TP removal in WTP reached 73.1%, the effluent phosphorus concentration still remained at enhanced levels. This can be attributed to the high portion of septage wastewater in influent and to an increased use of detergents in the tourist resorts. Effluent nitrogen is mainly present in the form of nitrates (NO_3) in relatively low levels as a result of nitrification–denitrification processes and does not appear to pose a significant risk for groundwater pollution (denitrification is achieved by the sequence of anoxic and anaerobic conditions).

With regard to electrical conductivity (EC), treated effluent is water with potential problems (Ayers and Westcot 1985). Likewise, increased concentrations of sodium (Na) and chloride (Cl) were assessed in treated effluent (Table 3). Thus, appropriate management practices should be adopted to eliminate adverse effects of salinity on plant growth and production. Such management practices include leaching of accumulated salts (Ayers and Westcot 1985), drip or subsurface irrigation (Oron and others 2002), and limiting effluent application to salt-tolerant species or genotypes (Paranychianakis and Chartzoulakis 2005). The levels of trace elements (Table 4) do not imply any risk for agricultural production, because their concentration is below the threshold concentrations suggested by Ayers and Westcot (1985). Apparently, more analyses on trace elements should be performed to ensure the safe use of the produced effluents in agriculture.

Average numbers of fecal coliforms (FCs) in the effluent exceeded the limits suggested by the US EPA (1992) and those proposed for unrestricted irrigation in Greece (Tsagarakis and others 2004). This fact, in conjunction with the great variation in the number of FCs, stresses the need for more careful management and reconsideration of disinfection processes to eliminate potential health risks associated with irrigation of green areas with treated effluent. These deviations can be attributed to overloading from septic wastewaters discharged in the WTP during summer months. On the other hand, the microbiological characteristics of the produced effluent do not appear to represent a significant risk for public health when used for irrigation of trees (WHO 1989, US EPA 1992).

Sludge Management

In the Hersonissos WTP, the produced sludge is digested and thickened to a SS concentration ranging from 2.5% to 3.5%. Removal of the volatile suspended solids (VSS) from sludge reaches 50%. Sludge thickening is not in operation due to low sludge flow rates, high-energy operational costs, and negligible sludge quality improvement at the decanters. The sludge is dewatered to a final SS concentration of 15–20%. A

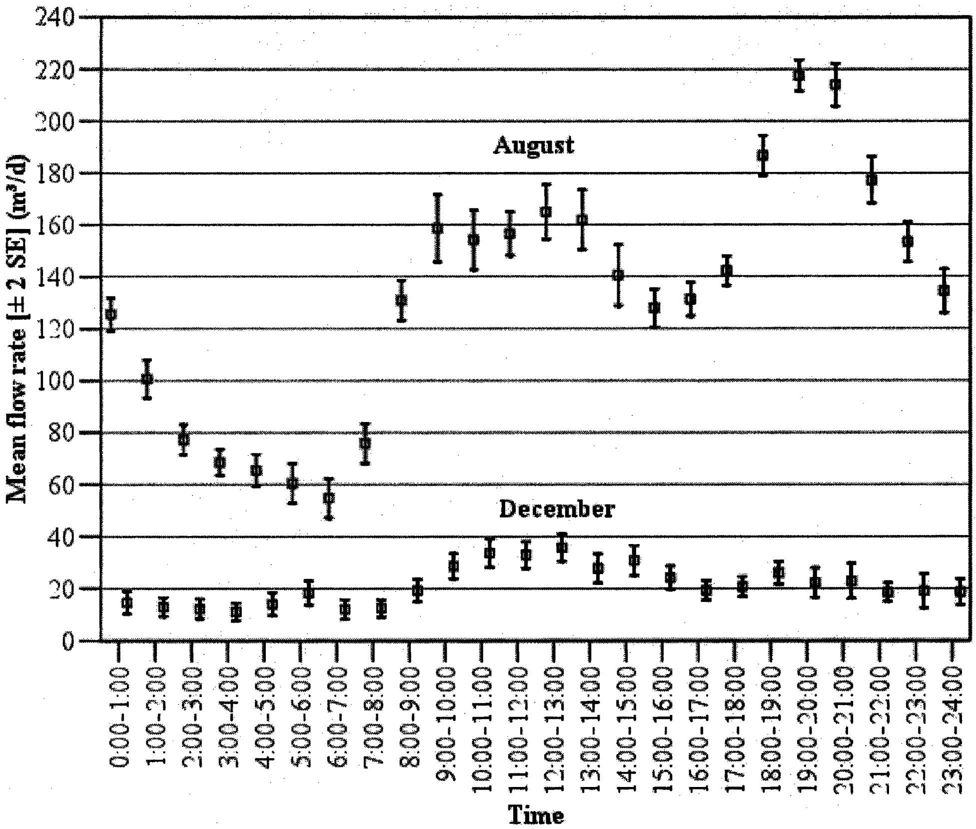

Figure 7. Hourly variations in volume for August and December.

Table 2. Quality characteristics of influent wastewater

Parameter[a]	Unit	Minimum	Maximum	Mean	Std. Dev.
BOD_5	mg/L	80	440	215	87
BOD_5[b]	mg/L	120	2120	634	283
COD[c]	mg/L	218	729	430	149
COD[b]	mg/L	420	20.235	3.196	3.849
SS	mg/L	140	540	204	92
SS[b]	mg/L	260	1880	747	386
TN	mg/L	14.00	62.00	33.62	12.15
TN[b]	mg/L	58.00	125.00	86.40	15.51
TP	mg/L	23.30	58.80	30.94	8.17
TP[b]	mg/L	17.50	98.00	50.86	25.01
pH	—	6.70	7.30	6.99	0.16
pH[b]	—	6.20	8.00	7.41	0.44

[a] Samples for the analysis were taken twice per week.
[b] Septic.
[c] chemical oxygen demand.

comparison of digested and dewatered sludge is given in Table 5. After centrifugation of the digested sludge, which results in a significant reduction in moisture content, the dewatered sludge generally becomes about five to six times drier than the digested one. Approximately 5.59 tons of polycationic coagulant (polyelectrolytes) are consumed annually to dewater the produced sludge (Figure 8).

Analyses of heavy metals and nutrients in the sludge were performed in two cases during 2003 (Table 6). The values are below the EU-proposed limits for sludge application to land (EU 1986, 2000). More samplings of the sludge should be performed to ensure its safe use for agricultural purposes.

The quantity of sludge produced is estimated to be approximately 2200 m^3/year (15.91% SS). The high

Table 3. Qualitative characteristics of secondary treated and filtered (SF) effluent

Parameter[a]	Unit	Minimum	Maximum	Mean	Std. Dev.
BOD_5	mg/L	2.00	24.00	11.33	5.12
COD	mg/L	25.00	92.00	53.84	18.54
SS	mg/L	0.25	47.00	7.66	7.97
TN	mg/L	0.90	26.00	6.03	6.14
TP	mg/L	0.01	18.30	6.06	5.44
pH	—	6.80	7.90	7.32	0.27
$N\text{-}NO_3$	mg/L	0.00	24.90	5.49	6.38
$N\text{-}NH_4$	mg/L	0.00	3.00	0.52	0.77
TC	CFU/100 ml	0.00	8600.00	1702.56	2607.88
FC	CFU/100 ml	0.00	2100.00	446.75	654.60
K	mg/L	16.00	58.00	27.51	7.86
EC	dS/m	2.34	2.84	2.59	0.13
Cl	mg/L	526.00	633.00	576.13	31.46
Na	mg/L	237.00	306.00	277.27	19.27
SF_pH	—	7.00	7.60	7.38	0.16
SF_SS	mg/L	0.25	10.75	4.46	2.83

[a]Samples for the analysis were taken twice per week, except microbiological parameters, which were taken once a month.

Table 4. Trace elements of treated wastewater

	Date of sampling	
Constituent	3/12/2003	8/28/2003
Cu (mg /L)	0.014	0.0225
Ni (mg/L)	0.012	0.01
Zn (mg/L)	0.37	1
Total Cr (Cr^{+3}, Cr^{+6}) mg/L	0.0036	<0.002
Cd (mg/L)	0.0048	0.0039
Pb (mg/L)	0.0064	0.0068
Bo (mg/L)	0.42	0.3

percentage of the septic wastewaters with a high SS content (Table 5) is mainly responsible for this increased sludge production. The fact that the WTP receives sludge for treatment from the wastewater treatment facilities of hotels and from the septic tanks of the surrounding areas also contribute to the high sludge production.

In other countries, sludge is further treated and applied to agricultural land (Matthews and Lindner 1996); however, in Greece almost 94% of the produced WTP sludge is disposed of in landfills (Tsagarakis 1999). Disposal of sludge poses many difficulties in Greece, such as the reduction of the lifetime of sanitary landfills. A solution to this problem would be the application of the sludge to agricultural land after chemical, biological, or thermal treatment, in agreement with to 86/278 Directive of the EU (EU 1986). Unfortunately, however, for the Hersonissos WTP, as with most WTPs in Greece, there are no such established or proposed treatment facilities, limiting the agricultural use of sludge.

Water Recycling Schemes

After receiving tertiary treatment in the Hersonissos WTP, effluent is used for the irrigation of agricultural land and landscapes and for fire protection. The municipality of Hersonissos encourages the use of treated effluent for these purposes in order to meet increasing water demands and to prevent aquifer salinization from sea intrusion (see Figure 3). An irrigation network has been established that serves the treated effluent for irrigation of agricultural crops, mainly the olive trees, which are the dominant crop in the surrounding area. The whole system is divided into two irrigation zones: a low zone (0–80 m above sea level) and high zone (70–100 m above sea level). The reuse infrastructure comprises the following units:

- A storage tank (V_{tank} = 300 m^3) at the plant exit.
- A pumping station with three pumps, two of which pump treated effluent to the high-zone irrigation tank (HZIT) (pump capacity: 167 m^3/h) and one to the low-zone irrigation tank (LZIT) (pump capacity = 152 m^3/h). The pumping station can be upgraded in the future, with up to eight pumps (four at the HZIT and four at the LZIT.
- An irrigation discharge pipe, with an overall length of 3.2 km.
- A central electromagnetic flow meter installed at the irrigation discharge pipe, and an electro-valve for selecting the irrigation zone (high or low) to be supplied with the reclaimed water.
- A LZIT (V_{tank} = 800 m^3, 100 m above sea level), with the possibility to build an additional tank of total volume 1600 m^3.

Table 5. Quality characteristics of sludge

Parameter[a]	Unit	Minimum	Maximum	Mean	Std. Dev.
Digested sludge	%[SS]	1.50	3.80	2.74	0.48
Dewatered sludge	%[SS]	12.65	19.29	15.91	1.39

[a]Samples for the analysis were taken twice per week.

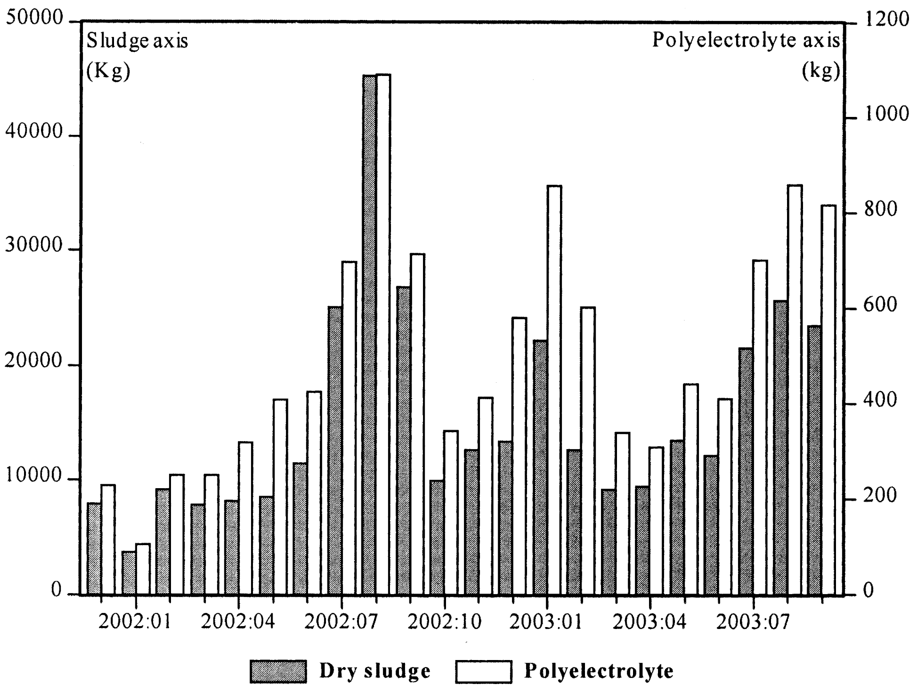

Figure 8. Dry sludge production per month and corresponding polyelectrolyte quantities.

Table 6. Chemical characteristics of sludge in the Hersonissos WTP compared to EU limits

	EU directive for agriculture reuse of sludge		Date of sampling	
Parameter	Proposed limits	EU 86/278	3/12/2003	8/28/2003
TP (%TS)				2.24
TN (%TS)				7.01
Ni (mg/kg dw)	300	300–400	40	<6
Zn (mg/kg dw)	2500	2500–4000	1230	3085
Total Cr (Cr^{3+}, Cr^{6+}) (mg/kg dw)	1000	—	5.8	40.7
Cd (mg/kg dw)	10	20–40	1	2.3
Cu (mg/kg dw)	1000	1000–1750	389	617
Hg (mg /kg dw)	10	16–25		9.7
Pb (mg/kg dw)	250	750–1200	13	146

- A HZIT (V_{tank} = 200 m^3, 140 m above sea level), with the possibility to build an additional tank of total volume 500 m^3.
- A low-zone irrigation pipe network.
- A high-zone irrigation pipe network with a total length of 2050 m irrigating an area of 200 ha.
- Forty-five irrigation collectors.
- Thirty-two fire hydrants.

Irrigation of Agricultural Land

Treated effluent is mainly applied to olive trees because they are the dominant crop in this area. It is estimated that there are approximately 135,000 olive trees in the Municipality of Hersonissos. Irrigation of olive trees with recycled water does not present a risk to public health, because the pathogenic populations fulfill the guidelines established by WHO (1989) and US EPA (1992) for the irrigation of fruit trees. Moreover, the adoption of drip irrigation systems by farmers, the late harvesting of trees (at least 1 month after irrigation has stopped), and the further processing of olives to produce oil eliminate health risks for both farmers and the public. Another advantage of olive trees is their high tolerance of salinity; hence, the relatively high concentrations of salts in the treated effluent do not pose a risk for yield (Paranychianakis and Chartzoulakis 2005). Treated effluent from the Hersonissos WTP can contribute water for increasing the area of irrigated land with olive trees. It is estimated that the total effluent produced is sufficient for the irrigation of at least 70 ha of olive trees if we take into account the crop coefficient k_c (= 0.7) (Allen and others 1998) and the ET of the area. The irrigation demand of olive trees in the Hersonissos area is shown in Figure 9. Given that olive tree requirements for the major nutrients N, P, and K are estimated to be approximately 200, 70, and 160 kg/ha, respectively, treated effluent can satisfy their needs for K and P, but additional N fertilization is required because N in effluent can cover only 25–30% of N demands. Therefore, the adoption of treated effluent for irrigation can be economically beneficial for farmers because it will reduce the application rates of commercial fertilizers.

Irrigation of olive trees in Hersonissos is applied from May to October; the storage of treated effluent during the period that it is not used for irrigation will increase the irrigated area of olive trees by approximately 10.4%. Alternatively, aquifer recharge during this period might be considered a cost-effective practice. This is expected to increase the water potential of the aquifer and improve its quality by preventing sea intrusion.

Landscape Irrigation

Apart from agricultural use, treated effluent is used for landscape irrigation. Two types of landscape irrigation are mainly practiced in Hersonissos: (1) irrigation of ornamental vegetation planted on the side slope of the new national road Iraklio–Ag. Nikolaos (7 km) and (2) irrigation of 5 ha of land planted with ornamental trees and scrubs in the surrounding areas of the five-star Creta Maris hotel and the four-star Silva Maris hotel (0.5 ha). Both hotels are located near the town of Hersonissos and are connected with the WTP sewerage network.

Fire Protection

Recycled water for fire protection is provided via the storage tanks used for agricultural irrigation. Water in these tanks never drops below 200 m^3, because this quantity is regarded as the minimum needed in the case of fire in the surrounding area. Fire hydrants have been installed in nearby residential and agricultural areas.

Environmental Benefits

Compared to traditional effluent management practices such as disposal to sea, rivers, or ephemeral streams, beneficial effluent reuse encompasses important environmental benefits (US EPA 1998). Reuse of treated effluent for agricultural and landscape irrigation in Hersonissos will contribute to the conservation of freshwater resources and their more rational usage, which is of paramount importance in this semiarid area. Thus, valuable freshwater resources will be used mainly for covering the increased urban demands during the summer period instead of irrigation purposes. In addition, beneficial reuse of treated effluent will alleviate the risks of sea intrusion in the coastal aquifer, which has seriously affected groundwater quality in Hersonissos (Figures 3 and 4) due to overexploitation of groundwater resources.

Agricultural reuse, if appropriately scheduled, can prevent stream and sea pollution resulting from the increased nutrient concentration (mainly nitrogen and phosphorus) found in the treated effluent. Furthermore, reuse will alleviate the health risks run by sea bathers, because thousands of tourists visit Hersonissos beaches during the summer. Finally, treated effluent can be used for the development of green areas, parks, and roadside slopes, which will increase the aesthetical value of Hersonissos. Low water availability and the semiarid climate of the area have limited the development of such areas.

Health and Safety

Given the current absence of effluent reuse regulations, not only in Greece but also in the European Union, the reuse of treated wastewater might cause serious health hazards if it is not carefully planned (Salgot and others 2003, Gerba and Rose 2003). Public awareness is essential when recycling projects are implemented, to prevent any accidental or improper use. To this end, notices have been placed stating the nonsuitability of the water for domestic use (e.g., drinking, washing). Educational programs from the municipality are scheduled to inform farmers on the safe use of the recycled water.

Farmers exhibit a positive attitude toward using the recycled water, and the willingness to use the effluent might increase with the availability of information on the advantages of this practice (Tsagarakis and Geor-

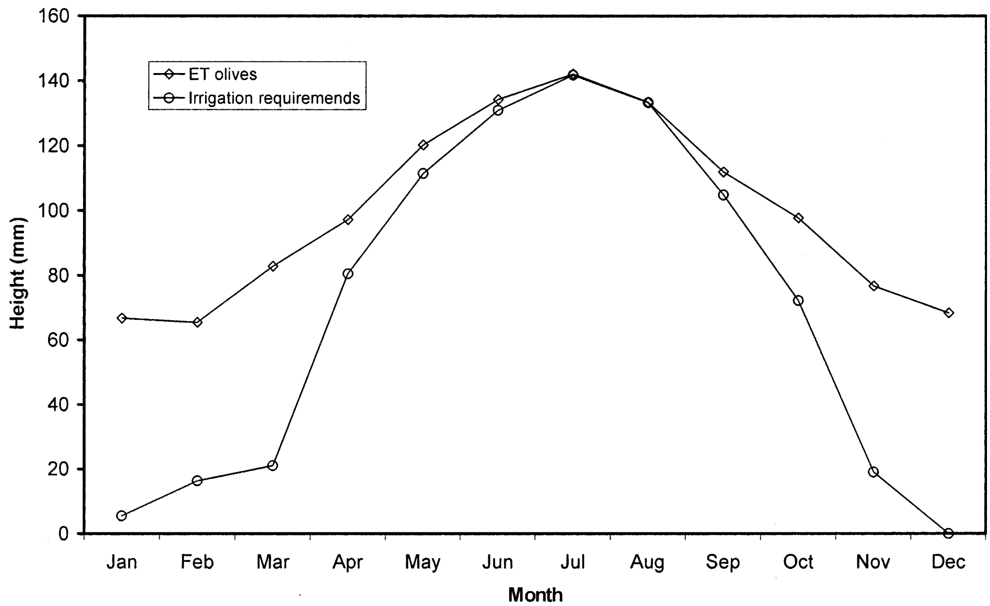

Figure 9. The ET of olive oil trees and irrigation demand of the Hersonissos area. The ET was calculated according to the Bland–Greddle method (Doorendos and Pruit 1977) and rainfall was adjusted to effective rainfall according to Dastane (1974).

gantzis 2003). The Municipality of Hersonissos has encouraged the use of treated effluent for purposes that eliminate health risks for both farmers and tourists. Although effluent recycling for landscape irrigation in hotels do not fulfill the limits suggested by international organizations and agencies, the adoption of practices such as subsurface or drip irrigation and the effluent application during the night hours diminish the risks resulting from contact.

Cost Analysis

The steps for the calculation of life costs are described in detail by Mara (1996) and Tsagarakis and others (2003). Taxes and other transfer costs are subtracted from the historical costs. Then these costs are referenced with respect to a base year. Capital costs are annuitized and are summed with the annual operation and management (O&M) costs to give the total annual economic cost (TAEC) (Figure 10). Thus, all prices must be reported to reflect early 2004 values. This analysis provides an economic value for each cubic meter cleaned, taking into consideration all of the stages of wastewater management. These are the costs for collection, secondary treatment, and reuse. Additional treatment, if required, will also have to be considered and, in the case of Hersonissos, filtration is examined separately, as it is used to provide effluent suitable for irrigation purposes. The methodology and analysis, based on raw cost data, are described as follows.

Subtract Any Taxes from the Historical Costs.

The money paid has to be revised to reflect the economic cost. To do so, any taxes have to be subtracted, as they are just a transfer of money. Therefore, the 18% value-added tax (VAT) has been subtracted from all applicable items.

Set Appropriate Discounting Rates

To correct historical values to the present, the appropriate rate is that which attributes to present-day costs, the same value as was used in previous years. The relevant rate for transferring historical costs (HCs) to present values (PVs) is, therefore, regarded as the inflation rate for this study. Inflation rates in Greece for the years 2000, 2001, 2002, and 2003 are 3.1%, 3.4%, 3.6%, and 3.8%, respectively.

The rate used as the opportunity cost of capital (OCC) is the one that subtracts expected inflation rates from the long-term borrowing rates ($r = R - f$). Both rates are subject to change over time. The study of historical values and knowledge of a country's economy are essential to make the best possible prediction. A high OCC can make long-term projects less preferable. Owing to the fact that the OCC is an estimation, a sensitivity analysis is recommended. A rate of 2% is regarded as the OCC in this study.

Make Definite Investigations and Decisions on Cost Parameters

All relevant costs should be included in these calculations including the cost of land, the capital, and all

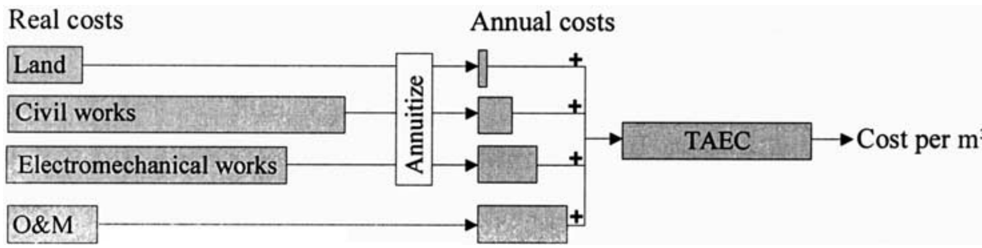

Figure 10. Costs calculations.

O&M costs. However, the cost of land is usually not included in these analyses, and O&M costs are often underestimated. Costs have been carefully taken from the invoices of the constructor and suppliers. This involved construction and O&M costs for the sewerage network, the WTP, and the filtration unit, as well as the cost of land. More detailed information on O&M cost data is provided in Table 7.

Table 7. Summary of the annual O&M costs

Cost category	Cost (€)
Personnel	276,739
Energy	135,610
Chemicals	45,173
Chemical analyses (subcontracting)	3,010
Transportation companies	1,328
Lubrication, gasoline, vehicle services	10,792
Electrical equipment	2,948
Hydraulic equipment and pipes	11,207
Machinery and tools	7,868
Subcontracting of other works	25,726
Other	10,956
Total	531,357

Calculate the Capital Recovery Factor

For a sanitation system that is fully utilized upon its completion, the cost calculations are simpler because all construction costs have been incurred in year 1, and the O&M costs remain the same each year. The construction costs are first annuitized (over the designed life of the system), using the OCC. The construction costs are annuitized by multiplying by a capital recovery factor (CRF):

$$CRF = \frac{r(1+r)^t}{(1+r)^t - 1} \qquad (1)$$

At this point, definite assumptions on the lifetime of the project should be made. For civil works, it is normally regarded as 40 years, and for electromechanical equipment, it is regarded as 15 years. Because this is estimation, a sensitivity analysis is recommended.

Calculate the Total Annual Economic Cost

The TAEC of the system is given by the sum of annuitized capital costs (C_c) and the annuitized operation and maintenance costs (C_a):

$$TAEC = (C_c \times CRF) + C_a \qquad (2)$$

It is assumed that the WTP is fully utilized from its first day of operation. This is the hypothetical optimal case. In reality, the influent gradually increases through time, until the full capacity of the plant is achieved. The TAEC is calculated as shown in Table 8. It can be concluded that the cost of construction and transportation of wastewater with the sewerage network, and treatment of 1 m^3 of wastewater will cost 0.12 € and 1.07 €, respectively. Additional treatment and irrigation infrastructure will require a further 0.05 € and 0.08 €, respectively (i.e., 12% surplus of the required secondary treatment).

Sensitivity Analysis

Sensitivity analysis is undertaken when there are factors that must be estimated. The estimations might differ because of uncertainty and, therefore, might considerably influence the economic analysis, leading to different conclusions. One of the factors to be monitored in this case is the lifetime of the project. Initially, it was regarded as 40 years for civil works and 15 years for electromechanical equipment. This might vary, however, due to the recent nature of these projects, continuously improving technology, or other parameters. The economy of the country might also influence the OCC, high values of which can make long-term projects look less attractive. Such an analysis will be necessary for the pricing strategy of the water companies. An unstable economy or too optimistic lifetime estimations of the projects will result in a much higher economic cost per treated cubic meter.

Table 8. Calculation of the TAEC for the individual stages of wastewater management

Cost category	PV (€)	Flow m^3/year	*r*	*t* (year)	CRF	AEC (€)	TAEC (€)	TAEC/m^3 (€)
Sewerage network		727,100						
Civil works	687,179		0.02	40	0.03656	25,121	87,195	0.12
Electromechanical works	431,861		0.02	15	0.07783	33,609		
O&M	28,465							
WTP		727,100						
Civil works	2,579,782		0.02	40	0.03656	94,305	778,576	1.07
Electromechanical works	1,925,101		0.02	15	0.07783	149,822		
Cost of land	84,548		0.02	40	0.03656	3,091		
O&M	531,357							
Filtration		580,721						
Civil works	80,543		0.02	40	0.03656	2,945	29,191	0.05
Electromechanical works	115,867		0.02	15	0.07783	9,017		
O&M	17,229							
Irrigation infrastructure		580,721						
Civil works	686,174		0.02	40	0.03656	25,083	44,454	0.08
Electromechanical works	97,862		0.02	15	0.07783	7,616		
O&M	11,754							
Total Cost								1.32

Conclusions

A comparison of flow rates at the Hersonissos WTP showed that daily variations differed by a factor of 12, from a minimum in winter to a maximum in the summer. An hourly variation in flow rates was also observed with an approximate fivefold increase, from a minimum daily average in winter to a maximum daily average in the summer.

Analysis of quality parameters reveals that although WTP performance on average achieves the quality levels of tertiary treatment, increased values of FC, SS, and BOD_5 can be observed during the peak flow in summer. For the FC levels in particular, the measured values exceeded the recommended safety limits for irrigating green areas and crops consumed raw. Thus, more emphasis should be given to the management and monitoring of the treatment plants in tourist resorts during the summer, to diminish potential health risks, especially when effluent reuse is practiced for uses involving a high degree of human contact. In tourist resorts, the efficient reuse of effluent for various uses can substantially alleviate demands for freshwater resources. Additional tertiary treatment units might be installed, such as constructed wetlands, purification ponds, or ultraviolet radiation. However, attention should be given to the presence of increased concentrations of salts, which miht impact plant growth and yield. Analysis of economic data shows that the cost per cubic meter of wastewater for collection, secondary treatment, additional treatment, and reuse is 0.12, 1.07, 0.05, and 0.08 €, respectively. Cost data should be analyzed to provide a potential value for assessing the use of recycled water as a tool for proper water management.

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