# IMPACT OF HUMAN ACTIVITIES ON THE QUALITY OF RIVER WATER: THE CASE OF EVROTAS RIVER CATCHMENT BASIN, GREECE

MICHAEL O. ANGELIDIS
*Department of Environment Studies, University of the Aegean, 17 Karantoni st., 81100 Mytilene, Greece*

and

PANAGIOTIS G. MARKANTONATOS and NIKIFOROS CH. BACALIS
*Environmental Design Ltd, Pontoiraklias 15, 115 27 Athens, Greece*

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**Abstract.** The impact of point (domestic and industrial effluents) and non-point (agricultural land runoff) pollution sources on the quality of the receiving waters of the Evrotas River (Laconia, Greece) was investigated during a monitoring study from August 1991 to August 1992. The part of the river which was located near the city of Sparta was seasonally influenced by the discharge of effluents from orange juice plants (operating during winter) and by the discharge of septage for the emptying of cesspools which are serving part of the city. The low dilution of incoming pollutants (septage) during the low water flow in summer lead to the decreasing self-purification capacity of the river and the development of septicity conditions in some of its parts. In the vicinity of intensively cultivated areas, the high concentrations of nitrogen and phosphorus which were detected in the river water during winter and spring may be partly attributed to the leaching of the applied fertilizers because of nirogen mobilization and soil erosion, following the season's precipitations. The protection of the Evrotas River water Quality must therefore include adequate treatment of the septage produced in the area, as well as the construction of wastewater treatment plants for the major industries of the area. The non-point pollution could be controlled by the restoration of the Evrotas riparian vegetation, together with a more rational use of fertilizers in the area.

## 1. Introduction

Rivers have been used since ancient times for transportation and water abstraction but also as repositories for wastes. Because humanity developed near fresh waters, rivers management has existed since antiquity. River management, according to traditional concept, is often connected with a variety of interventions into the river system aiming to maximize water resources, achieve flood protection, develop fisheries' capacity and lately improve recreational facilities (Boon, 1992; Newson, 1992). However, this kind of river management often leads to the deterioration of the riverine ecosystem in the form of water quality deterioration, removal of riparian vegetation, deforestation, water abstraction, flow regulation and development of human activities in the river basin area (Mellquist, 1992). Most of these activities, lead to the pollution of the river water by point and non-point pollution sources. Point pollution sources include domestic and industrial effluents, while runoff from intensively cultivated areas and urban centres constitute non-point pollution

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sources. Pollution is a relatively new by-product of river use and management, but in some areas has become an issue of primary concern. The quality of river water may vary depending on the geology morphology, vegetation and activities in the catchment basin, as well as on the location of the sampling site either upstream in the mountains or the lower reaches of the river course. Therefore it is difficult to set an absolute standard for river pollution. However, with the directive 75/440/EEC (for the use of surface water for drinking) the Commission of the European Communities (1975) set standards for different types of surface waters. The best quality of surface water must have (among others) the following characteristics: $BOD_5 < 3$ mg $l^{-1}$, suspended solids < 25 mg $l^{-1}$. $NO_3 < 25$ mg $l^{-1}$, $NH_4 < 0.05$ mg $l^{-1}$, $PO_4 < 0.4$ mg $l^{-1}$. Above these values, the water may be considered as not clean and can be consumed only after physical-chemical treatment and disinfection (chlorination, etc).

In Europe, pollutants of domestic, industrial and agricultural origin had seriously degraded the river water quality during the last century (Meybeck *et al.*, 1989). Point source pollution can be controlled effectively with the construction of treatment plants for domestic and industrial effluents. On the other hand, the control of non-point pollution for agricultural, urban and industrial areas is more difficult. Regarding eutrophication problems, nitrogen leaching to rivers in Europe and the USA may be considerable in the catchment basins with intensive agricultural activities. It may range from 800 to 3600 kg N $km^{-2}$ $yr^{-1}$ (Jackson *et al.*, 1973; Jaakola, 1984; Goffman *et al.*, 1986; Bergstorm, 1987). The amount of nutrients leached from the land varies depending on topography, soil texture, produced crop and agricultural practice. In the southern part of Europe, and especially in Greece, both point and non-point polution sources contribute to the deterioration of river water quality. Until very recently, few domestic wastewater treatment plants were in operation in Greece and consequently, in many cases, urban effluents are still being discharged untreated to the neighbouring watercourses (National Bank of Industrial Development, Greece, 1993). Industrial effluents are more efficiently controlled, but many small and medium size industrial plants (especially processing agricultural products) lack appropriate treatment facilities for their effluents. Therefore point pollution sources continue to be a major cause for the degradation of the surface water quality. On the other hand, because agriculture represents a major activity in Greece (with extensive use of fertilizers and pesticides), agricultural land runoff also plays a very important role in the degradation of the surface water quality. The effect of the fertilizers leaching into the river water may be more pronounced in areas were the riparian ecosystem has been destroyed (Petersen *et al.*, 1992). The riparian vegetation may act as a buffer system between the agricultural land and the receiving water body, retaining the nutrients and the eroded sediments (Lowrance *et al.*, 1984; Pinay and Decamps, 1988). Therefore, in the absence of such a retention buffer zone, the quasi-totality of the leached nutrients and pesticides will eventually reach the river water. Until now, few comprehensive surveys have been conducted in Greece to monitor river water quality or to evaluate the importance of point versus non-point pollution sources on a catchment basin scale. The scope of the present study was to investigate the above mentioned pollution mechanisms in the catchment basin of the river Evrotas, Greece, which may be considered as typical of many Greek and Mediterranean regions. The main characteristics of such regions are intensive agricultural activity (over-fertilization), small industrial activity related to the local agricultural products, and relatively small urban centres lacking adequate infrastructure for the management of their effluents.

## 2. Site Description and Pollution Sources

The Evrotas River basin covers the largest part of the Laconia Prefecture of Greece (Figure 1). The river is well known from the ancient history of Greece, because the mighty city of Sparta was located along its banks. Sparta is still the capital of the Laconia Prefecture with a population of 20 000 (National Statistics Service of Greece, 1991). The mean annual temperature in the city is 17.7 °C, while the mean monthly minimum temperature observed in January is 4.4 °C and the mean monthly maximum observed in August is 35.5 °C (National Meteorology Service of Greece, 1992). The mean annual precipitation in the area is 540 mm with a maximum 24 h precipitation of 56.3 mm. The majority of rainfall (47.4%) occurs in winter and only 2.5% occurs in summer months. The Evrotas River basin expands between the mountains of Taygetos (to the west) and Parnon (to the east) and has a total area of 1875 $km^2$. Evrotas River originates in the Taygetos mount, flows through the Laconia basin and outflows into the Laconikos gulf, with a total length of 82 km. The freshwater flow of the Evrotas River shows substantial seasonal variations, and is greatly affected by the annual precipitation (snowfall and rainfall in the surrounding mountains and the valley). Figure 2 presents the freshwater flow for the Evroras River, at the sampling station Vrondamas (middle reach of the river). It can be observed that the river flow exhibits intense fluctuations between winter and summer mainly because of the high slope and the small size of the river catchment basin. As a result, the river exhibits peak flows during heavy rainfall, while it becomes almost dry during the end of the summer (period of low rainfall). The river flow was further reduced in recent times, due to an extensive draught over the past four years and the high rate of use of surface and ground water sources for irrigation purposes. As a result, the drying of the river bed occurs almost every summer and extends over greater parts of the river course than in the past (Prefecture of Laconia, 1993).

The river along its course receives a variety of pollutants from point (urban and industrial effluents) and non-point (agricultural land runoff) pollution sources. The urban pollution originates from the direct or indirect disposal of sewage from the near-by communities into the river. The largest urban centre is the Municipality of Sparta, which since 1990 has operated a biological treatment plant serving the

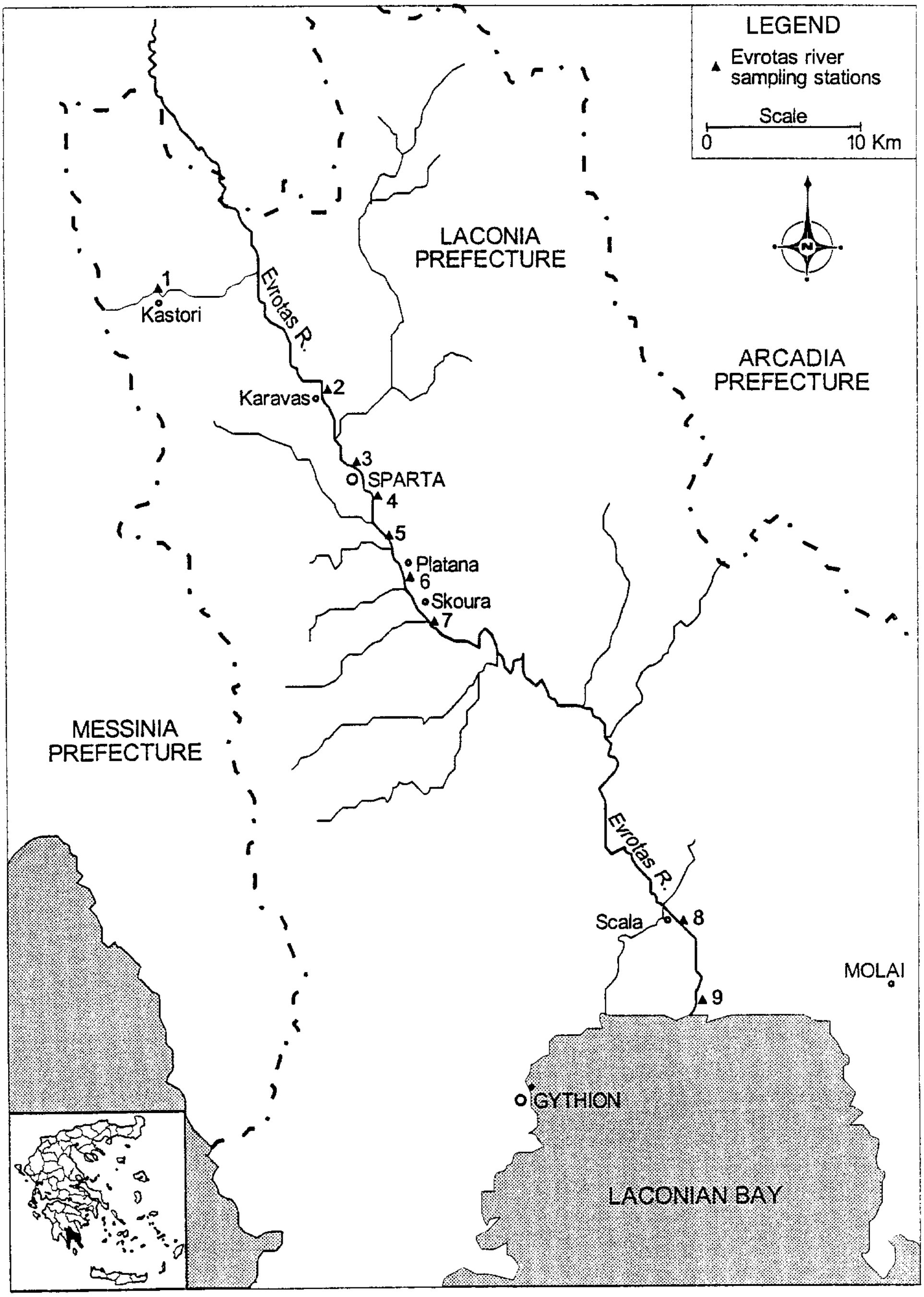


Fig. 1. Study area.

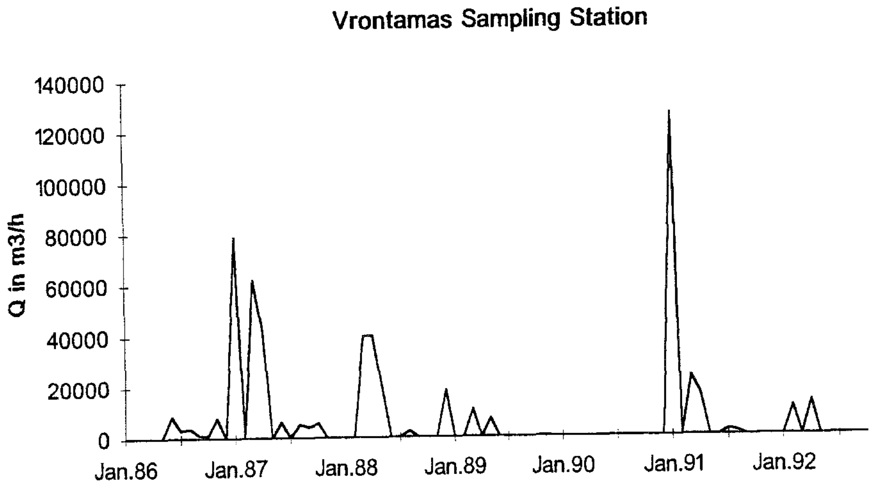


Fig. 2. Flow of the Evrotas River.

majority of the city (70%). However, the rest of Sparta and all the neighbouring communities are served by septic tanks and cesspools and their contents (septage) are usually disposed of into the river.

The economy of Laconia is based on agriculture. The main crops are oranges and olives, which are mostly cultivated in the plains of Sparta (orange trees 2850 ha, olive trees 14 650 ha) and Skala (orange trees 2650 ha, olive trees 7700 ha) (1 ha = 10 000 $m^2$). There are also ploughed cultivations, vine trees, vegetables and other tree planations covering smaller areas. The total irrigated land is 4330 ha in the Sparta area and 6100 ha in the Skala area. The use of fertilizers and pesticides in Laconia is intense with a total use of 35 000 tons of fertilizers in 1991. Ammonium sulphate, ammonium nitrate, ammonium phosphate and calcium-ammonium nitrate were the main types of fertilizers used. According to information from the Agricultural Association of Laconia (1992), the consumption of fertilizers for orange and olive trees is 5–8 kg $ha^{-1}$. However, it is estimated that the quantities which are acually used are much higher for orange trees because two crops are usually produced per year.

The industrial activity in Laconia is generally small and serves mostly agricultural production (orange juice production, small olive mills, meat processing, etc). Many of these activities are located within the Envrotas River basin and dispose their waste without adequate treatment, either directly into the river or in streams flowing into the river. The larger industrial units in the vicinity of the river are the plants producing, orange juice which have a seasonal operation and produce effluents with very high organic pollution load ($BOD_5$ 1200 mg $l^{-1}$).

## 3. Methodology

In order to study the impact of human activities on the river water quality, a monitoring programme of Evrotas River water quality was conducted, covering one full year, from August 1991 to August 1992. During this period, seven sampling expeditions were carried out (August and October 1991, February, March, April, July and August 1992), in which samples were collected from nine stations along the river (Figure 1).

Station 1 was located near the community of Kastori in the upper reach of the river near its springs, where the water was presumed to be clean. Station 2 was located near the community of Karavas, where the first major cultivations appear along the river. Stations 3, 4 and 5 were located near the city of Sparta, while station 6 was located near the community of Platana, downstream from the confluent of a highly polluted tributary of Evrotas. This tributary is periodically polluted from the waste of large orange juice factories. Station 7 was located near the community of Skoura and represents the last station in the intensively cultivated plain of Sparta. After this point, Evtotas enters a narrow valley with relatively few human activities. Stations 8 and 9 were located in the lower reach of the Evrotas River, along the intensively cultivated area of Skala.

Surface water samples were collected by immersion of pre-cleaned plastic bottles into the river water at a distance of 1.5–2 m from the river bank. The bottles were sealed and stored in the dark at 4 °C. For every period, samples were collected during the same day, from 07:00 h to 16:00 h. Diurnal fluctuations of the determined parameters were not taken into account. After collection, the samples were transported to the laboratory and were analyzed for biochemical oxygen demand ($BOD_5$), chemical oxygen demand (COD) [indicators of organic pollution], suspended solids (SS), nitrate ($NO_3$–N), ammonium ($NH_4$–N), Total N and Total P. Water temperature and dissolved oxygen were measured *in situ*, using portable equipment (WTW portable oxygen/temperature meter). Standard analytical methods were used for the determinations of all the parameters : $BOD_5$ by measuring the consumption of oxygen in 5 days (APHA *et al.*, 1985: method 507), COD with dichromate digestion (closed reflux, colorimetric method – APHA *et al.*, 1985, method 508 C), suspended solids, by filtration (0.45 $\mu$m filters) and determination of the weight of the solids. Nitrate ($NO_3$–N), $NH_4$–N, Total N and total P were determined by spectrophotometry, after colour generation, using respectively the following methods: Method 418 C, for nitrate (APHA *et al.*, 1985), method 417B for ammonium (APHA *et al.*, 1985), digestion with sodium persulphate followed by nitrate determination (method 418 C) for total nitrogen and method 424 D, for total phosphorus (APHA *et al.*, 1985). All analytical methods are described in detail in the *Standard Methods for the Examination of Water and Wastewater* (APHA *et al.*, 1985, 16th ed). The overall relative standard deviations of the methods used were: $BOD_5$ 10%, COD 8%, SS 5%, $NO_3$–N 3% NH–$_3$N 5%, Total N 5% and Total P 15%.

TABLE I

$BOD_5$, COD, SS, DO, total N, total P, $NO_3$ and $NH_4$ concentrations (mg/l) in Evrotas River

| Period | Station | $BOD_5$ | COD | SS | DO | Total N | Total P | $NO_3$–N | $NH_4$–N |
|---|---|---|---|---|---|---|---|---|---|
| August | 1 | | | | | | | | |
| 1991 | 2 | | | | 10.40 | 9.10 | 0.40 | | |
| | 3 | | 6.00 | 8.00 | 7.10 | 8.00 | 0.30 | | |
| | 4 | | | | | | | | |
| | 5 | | | | | | | | |
| | 6 | | | | | | | | |
| | 7 | | 6.00 | | 11.10 | 6.00 | 0.70 | | |
| | 8 | | 9.00 | 9.00 | | 10.00 | 0.60 | | |
| | 9 | | 30.00 | 20.00 | 6.40 | 16.00 | 0.90 | | |
| October | 1 | N.D. | N.D. | N.D. | 10.10 | 0.10 | N.D. | 0.10 | N.D. |
| 1991 | 2 | N.D. | 6.00 | N.D. | 13.70 | 1.80 | 0.08 | 1.50 | 0.06 |
| | 3 | 3.00 | 6.00 | N.D. | 9.70 | 2.60 | 0.05 | 2.30 | 0.10 |
| | 4 | 6.00 | 18.00 | 5.00 | 3.60 | 3.80 | 0.15 | 3.20 | 0.20 |
| | 5 | | | | | | | | |
| | 6 | | | | | | | | |
| | 7 | 4.00 | 12.00 | N.D. | 12.90 | 5.00 | 0.05 | 4.20 | 0.30 |
| | 8 | | | | | | | | |
| | 9 | 5.00 | 12.00 | N.D. | 9.50 | 0.60 | 0.20 | 0.30 | 0.08 |
| February | 1 | N.D. | N.D. | 10.00 | 11.00 | 0.20 | N.D. | N.D. | N.D. |
| 1992 | 2 | N.D. | 9.00 | 5.00 | 12.40 | 0.60 | N.D. | 0.40 | N.D. |
| | 3 | 5.00 | 9.00 | N.D. | 13.70 | 3.10 | 0.07 | 2.80 | 0.50 |
| | 4 | 8.00 | 15.00 | N.D. | 14.60 | 6.00 | 1.30 | 4.70 | 0.90 |
| | 5 | 12.00 | 21.00 | 16.00 | | 8.00 | 3.00 | 5.20 | 2.40 |
| | 6 | 40.00 | 126.00 | 85.00 | 6.20 | 19.00 | 4.20 | 14.00 | 3.80 |
| | 7 | 25.00 | 66.00 | 60.00 | 11.70 | 12.00 | 3.00 | 9.00 | 2.10 |
| | 8 | 20.00 | 45.00 | 35.00 | 9.00 | 9.00 | 1.90 | 7.00 | 1.70 |
| | 9 | 4.00 | 18.00 | 10.00 | 9.50 | 1.00 | 0.06 | 0.80 | 0.05 |
| March | 1 | N.D. | N.D. | 12.00 | 11.00 | 0.60 | N.D. | N.D. | N.D. |
| 1992 | 2 | N.D. | N.D. | N.D. | 11.60 | 0.30 | N.D. | N.D. | N.D. |
| | 3 | 28.00 | 45.00 | 65.00 | 7.60 | 11.50 | 3.00 | 7.30 | 2.40 |
| | 4 | 5.00 | 15.00 | 5.00 | 10.20 | 3.70 | 0.90 | 3.10 | 2.00 |
| | 5 | 5.00 | 18.00 | 10.00 | 8.00 | 4.00 | 1.30 | 2.80 | 2.00 |
| | 6 | 37.00 | 90.00 | 100.00 | 10.60 | 12.60 | 4.00 | 11.00 | 4.30 |
| | 7 | 18.00 | 39.00 | 45.00 | 11.00 | 9.00 | 4.10 | 6.20 | 1.90 |
| | 8 | 15.00 | 30.00 | 30.00 | 10.60 | 7.20 | 2.10 | 4.90 | 1.40 |
| | 9 | 8.00 | 21.00 | 18.00 | 9.10 | 2.00 | 0.20 | 1.50 | |
| April | 1 | N.D. | N.D. | 8.00 | 9.50 | 0.45 | N.D. | N.D. | N.D. |
| 1992 | 2 | N.D. | N.D. | N.D. | 9.70 | 0.20 | N.D. | N.D. | N.D. |
| | 3 | 45.00 | 99.00 | 155.00 | 6.70 | 15.00 | 4.00 | 6.00 | 7.50 |
| | 4 | 20.00 | 42.00 | 37.00 | 10.30 | 5.40 | 1.30 | 3.70 | 3.00 |

TABLE I
*Continued*

| Period | Station | $BOD_5$ | COD | SS | DO | Total N | Total P | $NO_3$–N | $NH_4$–N |
|---|---|---|---|---|---|---|---|---|---|
| | 5 | 17.00 | 30.00 | 25.00 | 10.10 | 4.40 | 1.00 | 3.00 | 1.80 |
| | 6 | 12.00 | 21.00 | 17.00 | 8.30 | 11.20 | 4.30 | 9.00 | 4.00 |
| | 7 | 3.00 | 12.00 | 10.00 | 10.30 | 5.20 | 2.00 | 4.00 | 0.90 |
| | 8 | 18.00 | 75.00 | 35.00 | 8.80 | 9.50 | 1.40 | 3.10 | 7.20 |
| | 9 | 10.00 | 45.00 | 5.00 | 4.20 | 8.10 | 1.40 | 0.70 | 7.10 |
| July | 1 | N.D. | N.D. | 4.00 | 10.40 | 0.60 | N.D. | N.D. | N.D. |
| 1992 | 2 | N.D. | N.D. | N.D. | 11.30 | N.D. | N.D. | N.D. | N.D. |
| | 3 | 95.00 | 210.00 | 165.00 | 2.30 | 21.00 | 3.80 | 9.00 | 11.20 |
| | 4 | 6.00 | 21.00 | 17.00 | 15.80 | 6.20 | 0.90 | 3.80 | 4.00 |
| | 5 | 9.00 | 27.00 | 20.00 | 14.10 | 3.00 | 0.90 | 3.00 | 0.90 |
| | 6 | 6.00 | 21.00 | 10.00 | 5.50 | 8.00 | 2.10 | 6.20 | 2.00 |
| | 7 | 0.00 | 15.00 | 8.00 | 8.60 | 4.00 | 0.90 | 1.20 | 1.90 |
| | 8 | 9.00 | 39.00 | 27.00 | 9.50 | 6.80 | 1.20 | 2.60 | 3.70 |
| | 9 | 7.00 | 33.00 | N.D. | 5.30 | 6.00 | 1.10 | 1.50 | 4.00 |
| August | 1 | N.D. | N.D. | 12.00 | 9.70 | 0.30 | N.D. | N.D. | N.D. |
| 1992 | 2 | | | | | | | | |
| | 3 | 23.00 | 45.00 | 45.00 | 5.70 | 10.70 | 3.50 | 6.00 | 4.10 |
| | 4 | 12.00 | 30.00 | 20.00 | 3.20 | 4.90 | 1.30 | 3.30 | 2.80 |
| | 5 | 19.00 | 33.00 | 30.00 | 19.50 | 7.00 | 2.00 | 4.20 | 1.90 |
| | 6 | 20.00 | 36.00 | 40.00 | 1.30 | 9.00 | 3.20 | 7.00 | 1.90 |
| | 7 | | | | | | | | |
| | 8 | | | | | | | | |
| | 9 | 5.00 | 18.00 | N.D. | 4.20 | 3.00 | 1.40 | 2.10 | 1.40 |

N.D. = Non detectable.

## 4. Results and Discussion

The results of the analyses are presented in Table I. The results will be presented and discussed for the four seasons: summer–autumn 1991 (dry period), winter 1992 (rainy season, operation of the agricultural industries), spring 1992 and summer 1992 (dry season).

### 4.1. Summer (August) and Autumn (October) 1991

During the sampling period of August and October 1991, a great part of the river bed was dry because of the combined impact of the lack of rainfall and the intensive water abstraction from the river for irrigation. As a consequence, the sampling covered only part of the river course (Table I). As a general view, in both seasons, the concentrations of all parameters remained relatively low, compared with the data from winter and spring. The highest concentrations of organic matter ($BOD_5$ and COD) were detected in October at station 4, near the city of Sparta and were attributed to the combined effect of domestic dischanges and the low water flow (low dilution). The nitrogen concentration along the river was relatively low (Table I), with the highest values occurring at station 7 near the agricultural area of Skoura (total N: 5.0 mg $l^{-1}$). The main form of nitrogen was nitrate ($NO_3$–N: 4.2 mg $l^{-1}$), indicating that full nitrification had already occurred. Phosphorus concentration was very low in all stations and may be related to the absence of fertilization during this period and to the relatively low concentration of suspended solids in the river water. In a greater part of the river the water quality was satisfactory, with high concentrations of dissolved oxygen (D.O. 8.0–13.7 mg $l^{-1}$).

### 4.2. Winter (February) 1992

The main characteristics of this period are the operation of the orange juice industries south of the city of Sparta and the increased river flow due to the winter precipitations in the Laconia basin. The orange juice industries operate seasonally because oranges are produced mainly during winter. The operation season (depending on the yield of the year) includes a peak period (full operation) from December to February and a low period (partial operation) from March to April. After April the orange processing plants cease operation. The larger orange juice producing unit of the area is located near the city of Sparta and has as operating capacity of 160 tonnes of oranges/8 h. The daily discharged effluents during the peak period are 100 $m^3$/h, and have the following, characteristics: pH 9.6, $BOD_5$ 1140 mg $l^{-1}$. COD 2550 mg $l^{-1}$ and SS 2800 mg $l^{-1}$ (DEYAS, 1993).

The industrial effluents are discharged into a small tributary of the Evrotas River, upstream from station 6. A survey of the water quality of this tributary during the plant's operation (26/2/92) revealed extensive pollution: $BOD_5$ 120 mg $l^{-1}$, COD 540 mg $l^{-1}$. Furthermore, the colour of the river water was yellow, with floating remains of oranges. At station 6, $BOD_5$ and COD reached concentrations of 40 mg $l^{-1}$ and 126 mg $l^{-1}$ respectively, indicating the serious impact of orange juice plant effluents on the river water quality, since at station 5, before the inflow of the polluted tributary, the same parameters were 12 mg $l^{-1}$ and 21 mg $l^{-1}$, respectively (Table I). Downstream from station 6, organic matter and nutrients concentration decreased gradually because of dilution and the self purification capacity of the river (Figures 3 and 4).

An initial estimation was made on the influence of the orange juice producing plant on the organic load ($BOD_5$) of the river. With a river flow of 2800 l $h^{-1}$ (Vrondamas measuring station, 26/2/92), and because the added $BOD_5$ from station 5 to station 6 is 40–12 mg $l^{-1}$ = 28 mg $l^{-1}$, the total added $BOD_5$ to the river is 78.4 g $BOD_5$ $s^{-1}$. The organic load of the industrial effluent is estimated to be:

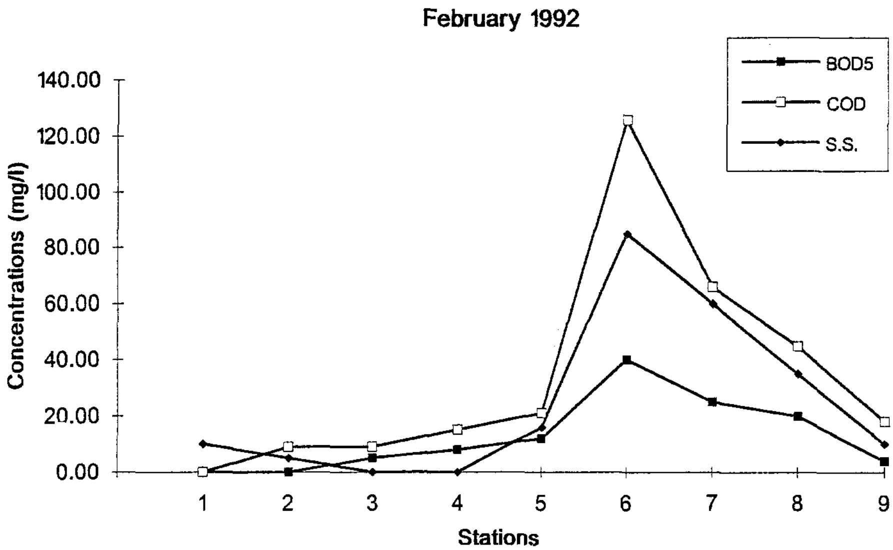


Fig. 3. $BOD_5$, COD and SS concentrations in the Evrotas River (February 1992).

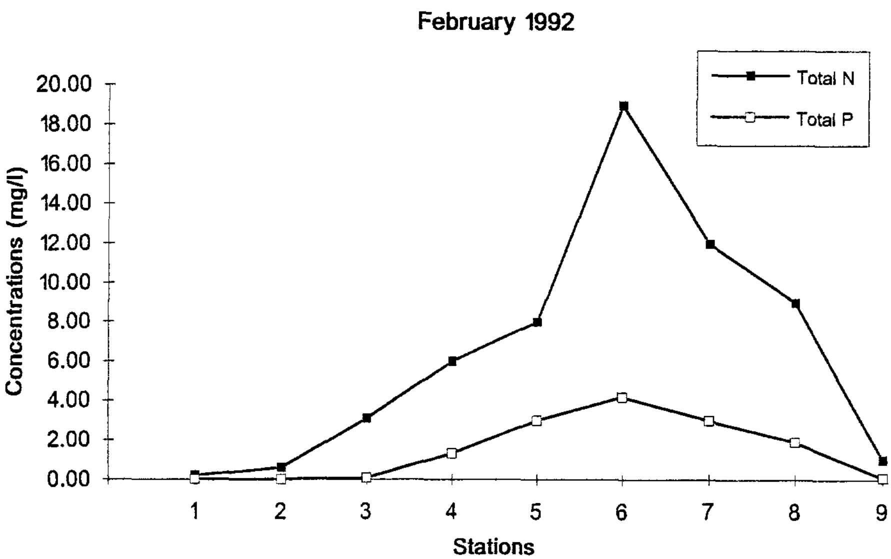


Fig. 4. Total N and total P concentrations in the Evrotas River (February 1992).

$1140\ \mathrm{mg\ l^{-1}} \times 100\,000\ \mathrm{l\ h^{-1}} \times 16\ \mathrm{h\ day^{-1}} = 1824\ \mathrm{kg\ BOD_5\ day^{-1}}$, or 21 g $BOD_5$ $s^{-1}$. That means that at lest 27% of the increase of $BOD_5$, from station 5 to station 6, is due to the industrial effluents discherged through the specific tributary. The remaining BOD increase in the river may be attributed either to the re-suspension of the orange pulp deposition on the river bed in the area, or to other pollution sources (i.e. agricultural land runoff). Of course these are gross estimations, containing an important factor of error, since no flow measurements are available in this specific part of the river (Vrondamas measuring station is located 20 km downstream from station 6) and the organic load data used for the estimations represent only one sample. Nevertheless, the above exercise gives an idea of the potential impact of the orange juice producing plant on the river water quality at station 6.

However, the effluents from orange processing plants, are not the only pollution source during the winter period. The increased concentration of nitrogen and phosphorus which were observed in station 6 (total N 19 mg $l^{-1}$ and total P 4 mg $l^{-1}$) cannot be solely attributed to the industrial effluents since the latter are not expected to contain high nutrient concentrations. On the other hand, it is well documented that nutrients stored in agricultural land over the dry season may be mobilized during the rainy season and subsequently transported to the receiving river waters via surface runoff of ground water infiltration (Owens, 1970; Esser and Kohlmaier, 1991; Ministry of the Environment Denmark, 1991). Hence an important fraction of fertilizers, applied previously to agricultural land, will eventually reach the receiving ground and surface waters. Nitrogen is more easily leached because of the high solubility of its compounds (ammonia, nitrate and nitrite are all very soluble). On the other hand, phosphorus is mostly transported in association with particulate matter reaching the rivers through erosion of the cultivated soil (Kempe *et al.*, 1991). Since February is a month with important rainfalls in the plain of Laconia, it may be assumed that at least part of the nutrients found in the Evrotas water in areas of intense agricultural activity may have reached the river through fertilizer runoff from the cultivated lands. This may be the case at stations 5, 6 and 7, along the intensively cultivated plain of Sparta (Figure 4). The area had previously encompassed and extended riparian forest (mainly *Platanus orientalis*), which is now mostly destroyed because of clear-cutting for agricultural land reclamation. The absence of a sufficient buffer zone between the cultivated areas and the river water, may facilitate the transport of nutrients and eroded soil, to the Evrotas River.

### 4.3. Spring (March-April) 1992

During the sampling periods of March and April, the industrial activity of the orange juice plants diminished gradually and subsequently the organic load in station 6 decreases considerably (March: $BOD_5$ 37 mg $l^{-1}$, COD 90 mg $l^{-1}$; April: $BOD_5$ 12 mg $l^{-1}$, COD 21 mg $l^{-1}$, Table I). On the other hand, during spring, increased concentration of organic matter was found in station 3, at the bridge of Sparta (Figure 5, April 1992). The $BOD_5$ concentration in this station during March and April 1992 was 28 mg $l^{-1}$ and 45 mg $l^{-1}$ respectively and probably reflected the discharge of cesspools contents directly into the river, at a location 200 m upstream from the Sparta Bridge. This discharge point was activated in early 1992, after the opening of a small road towards the river. The septage discharges also affected the concentration of nutrients in station 3 (Figure 6). However, relatively increased

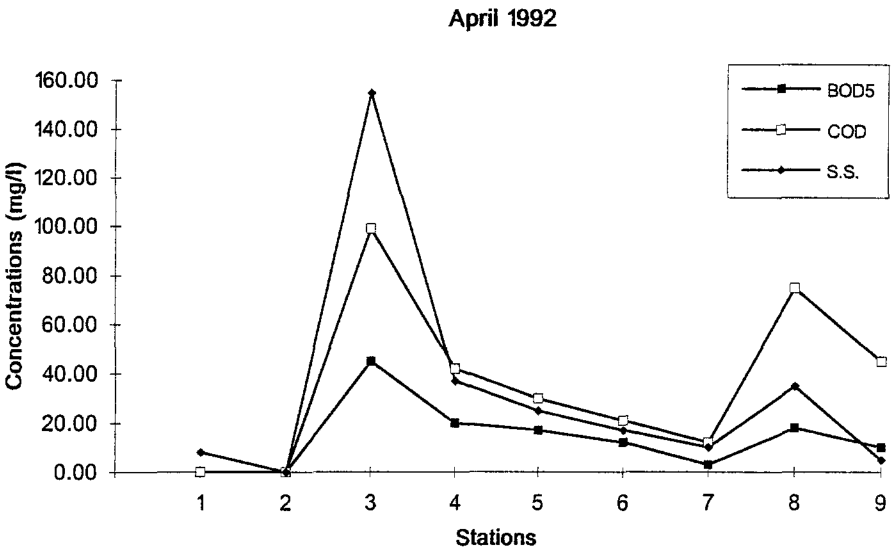


Fig. 5. $BOD_5$, COD and SS concentrations in the Evrotas River (April 1992).

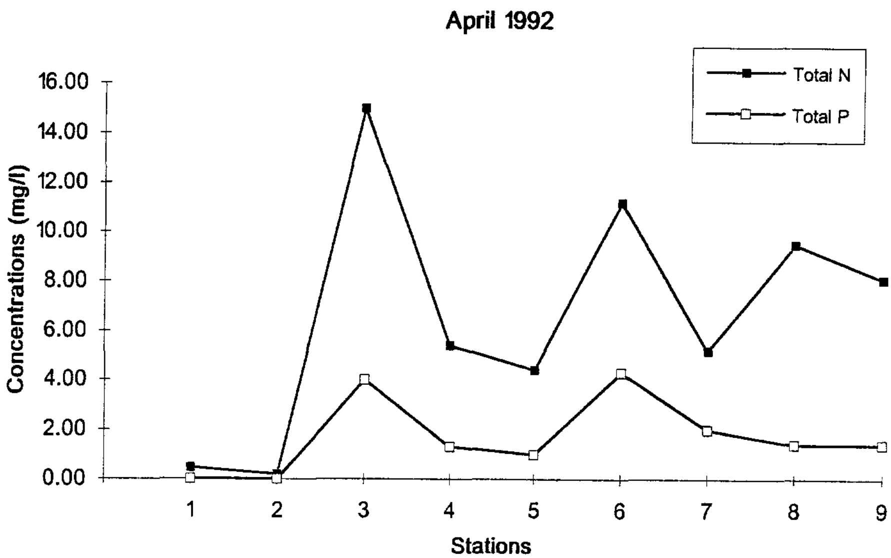


Fig. 6. Total N and total P concentrations in the Evrotas River (April 1992).

N and P concentrations were also found during the same months, in stations 6, 8 and 9. It was estimated that the fertilizers runoff from the intensively cultivated areas of Sparta (station 6) and Skala (lower reach of Evrotas, stations 8 and 9) may have had an impact on the river water quality during early spring. According to the information from the Agricultural Association of Laconia (1992), the main species cultivated in these areas are orange and olive trees. Orange trees are mostly

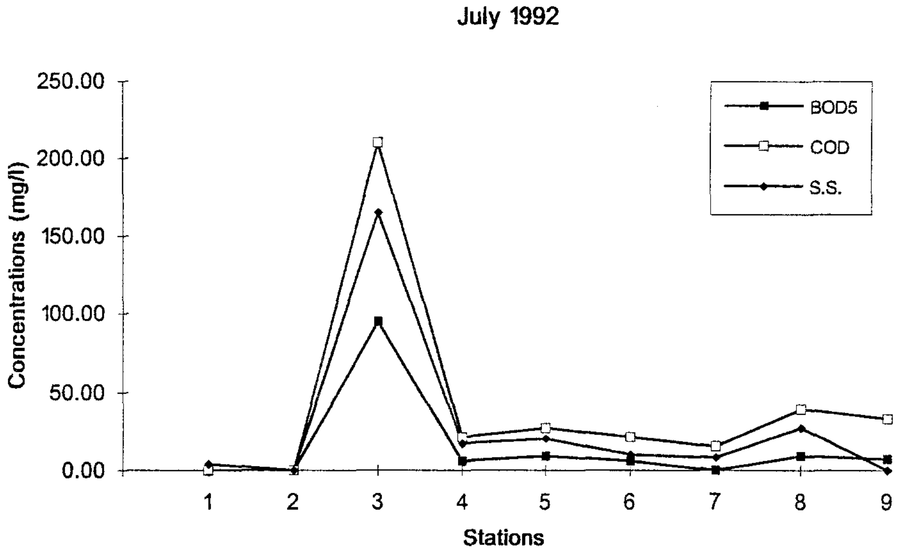


Fig. 7. $BOD_5$, COD and SS concentrations in the Evrotas River (July 1992).

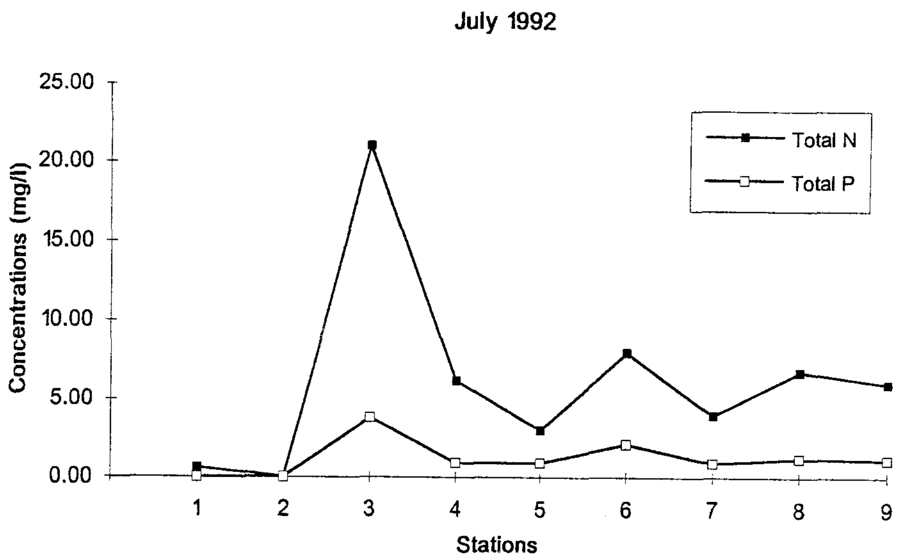


Fig. 8. Total N and total P concentrations in the Evrotas River (July 1992).

cultivated in the vicinity of the river and the application of fertilizer takes place during spring and summer. Olive trees are less intensively cultivated and are located at greater distance from the river, towards the slopes of the catchment basin. Their fertilization takes place in February.

### 4.4. Summer (July and August) 1992

During the summer months the river flow was again seriously reduced, leading to the complete drying of the river bed in some parts of its course, in August. Pollution caused by septage discharge continued to increase, at station 3, during July ($BOD_5$ 95 mg $l^{-1}$ and COD 210 mg $l^{-1}$, Figure 7) because of the decreasing dilution in the reduced water flow. Very low concentrations of dissolved oxygen were detected in this station (2.3 mg $l^{-1}$) and the characteristic odour of septicity, which was distinct near the river banks, suggested the occurrence of anaerobic conditions in the river sediments. Nitrogen and phosphorus concentrations were also high in station 3 (Total N 21 mg $l^{-1}$, $NH_4$–N 11.2 mg $l^{-1}$, total P 3.8 mg $l^{-1}$, Figure 8). Downstream from station 3, the concentrations of all the pollutants decreased considerably and remained relatively low along the river course. The other pollution sources seem to have minor impact on the river water quality during this season since industrial activity (mainly orange processing) has ceased because of the season and the nutrients runoff from the cultivated areas is seriously diminished due to the lack of precipitation during the summer months.

During August 1992, the river bed was dry in many parts of its course and therefore it was not possible to follow the fluctuations of the pollutants along the river. The river discharge was very low in the non-dried parts of the river, leading to little dilution of the incoming pollutants. Although no general conclusions can be drawn on the behaviour of pollutants in the river during this period, important improvement was witnessed in the river water quality near the city of Sparta (Table I). In early August, a septage treatment facility was commissioned in the Municipal Wastewater Treatment Plant of Sparta and the septage discharge to the river was discontinued. As a result, the organic pollution declined considerably during August ($BOD_5$ 23 mg $l^{-1}$ and COD 45 mg $l^{-1}$), compared with the previous month. On the other hand, the concentration of organic load ($BOD_5$) in all the stations at this part of the river (stations 3, 4, 5 and 6) remained relatively high, indicating the reduced self-purification capacity of the river, which may be attributed to the extremely low water flow during that season.

## 5. Conclusions

The seasonal monitoring of the main pollution parameters in the Evrotas River led to certain conclusions on the factors of river pollution and the mechanisms of self-purification.

A. The effluents discharged by the orange juice plants which are operating in the Sparta plain appear to be the main cause for the extremely high concentrations of organic matter found during the winter months at stations 6 and 7. The organic load at those stations decreased in spring and summer, when the orange processing plants cease their operation (Figure 9). On the other hand, the high nitrogen concentrations

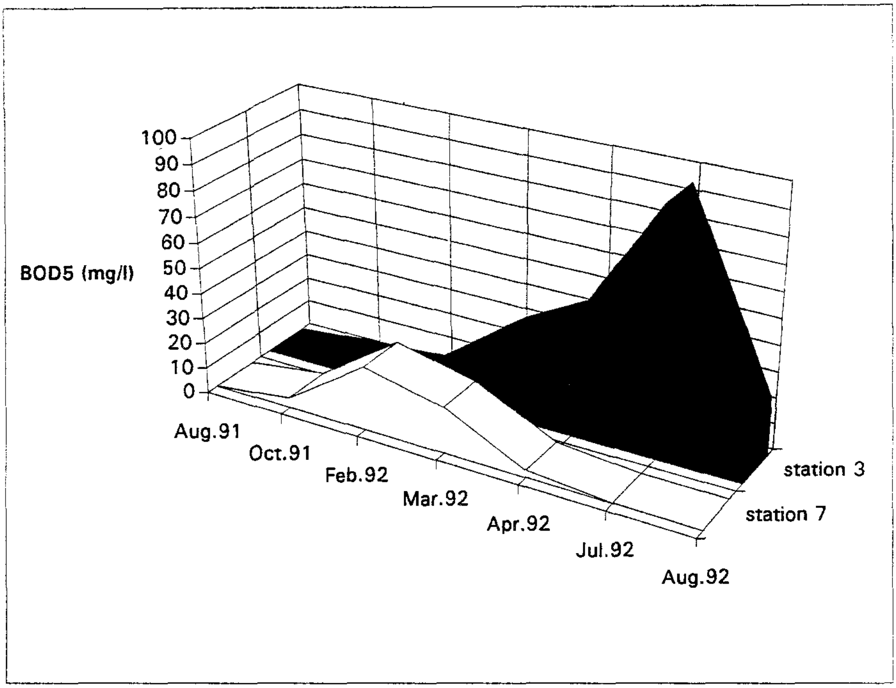


Fig. 9. Seasonal $BOD_5$ concentrations at stations 7 and 3 (August 1991 – August 1992).

found during winter and spring, in the part of the river which is flowing through the plain of Sparta, may be only partially attributed to the industrial effluents discharges (winter period) and partially to the leaching of fertilizers from the cultivated areas, which is caused by the intensive rainfalls of the season (winter and spring). The leaching of fertilizers from cultivated areas (orange trees) may also be the cause of the relatively enhanced nitrogen and phosphorus concentrations in the lower reach of the river during spring (station 8, near the town of Skala).

B. The urban septage discharges into the river was an important factor for the deterioration of the Evrotas River water quality, especially near the city of Sparta (station 3). The impact of the discharged septage on the water quality increased from early spring towards the summer months (Figure 9), because of lower dilution in the gradually reduced water flow of the river. Extremely high values of organic matter were witnessed during July 1992, which led to a marked decrease of dissolved oxygen concentration in the river water and the occurrence of odours indicating septicity conditions in the river bed. The commissioning of a septage treatment facility in the area led to the interruption of septage discharge into the river and to an improvement of the water quality in the area.

C. Evrotas River has an intermittent flow during summer months. During these months, the self-purification capacity in the river decreases due to the low water flow, as was apparent by the consistent high organic matter concentrations from stations 3 to 6, in August 1992. However, the river water outflowing into the Northern Laconikos gulf during the greater part of the year does not contain high concentrations of pollutants, although occasional peaks may occur. The reed bed formations at the lower reach of the river may be reponsible for nutrient retention through mechanisms of suspended solids trapping, denitrification and plant assimilation.

In conclusion, it was realized that point pollution sources caused acute pollution problems in the Evrotas River near the city of Sparta. Septage discharges (especially during the period of low water flow in summer) and industrial effluents (during winter) were the main reasons for the degradation of the river water quality. These pollution sources however are already in the process of being controlled with the commissioning of a municipal septage treatment unit and the construction of wastewater treatment plants in the orange processing industries. On the other hand, non-point pollution sources seem to be more difficult to handle successfully. The control of the use of fertilizers by farmers and the restoration of the riparian forest along the river are among the possible measures to be taken to protect the river water quality. In order to implement these measures, an Authority must be established on a catchment basin scale (Gardiner 1991) for the Protection and Management of Evrotas River.

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