# AN INTEGRATED WATER POLLUTION CONTROL PROJECT TO PROTECT GROUNDWATER OF ANTALYA PLAIN FROM DIFFUSED SOURCES


[*]Ayse Muhammetoglu, [**]Ozgur Bulent Yalcin

[*]*Environmental Pollution and Control Program, Akdeniz University, 07059 Antalya, Turkey*
*Tel: +90 242 227 47 80 Ext. 4129 Fax: +90 242 227 47 85, (E-mail: muhammetoglu@usa.net)*
[**] *Environmental Engineering Department, Akdeniz University, 07059 Antalya, Turkey*
*Tel: +90 242 323 68 90 Fax: +90 242 323 23 62, (E-mail: obyalcin@yahoo.com)*



## ABSTRACT

Antalya city, located along the Turkish Mediterranean coast, has a population of about one million capita. The city lacked proper wastewater collection, treatment and disposal systems until recent years. As a result, groundwater levels of some major pollutants such as nitrate and coliform bacteria have shown an unacceptable and increasing trend over the years. Since groundwater is the main water supply resource for the city, an integrated water and wastewater project has been initiated to protect the drinking water resources and the seawater quality. The project involved collection, treatment and disposal of the wastewater. The final disposal was planned and designed as a long and deep sea outfall. A seawater quality-monitoring program, which includes seasonal field measurements and lab analyses, has been launched to determine the impact of the sea outfall on the quality of the seawater. The governing dilution levels of the discharged effluents around the sea outfall have been computed using the results of the water quality monitoring program. The calculated dilution levels exhibited considerable spatial and temporal variations. Moreover, the calculations showed that the discharged wastewater will always remain submerged below the seawater surface, which agrees with the results of the monitoring program.



**Keywords : Antalya, coliform, dilution, groundwater, nitrate, sea outfall**


## INTRODUCTION

Antalya is a crowded city located on the Turkish Mediterranean coast. The city is a center of attraction for tourism, agriculture and settlement because of its rich natural, archeological and cultural resources. Therefore, the city became one of the most preferred domestic immigration destinations in Turkey in recent years. As a consequence of high domestic immigration levels, the average population increase rate was extremely high and it was about 4.7% between 1990 and 2000 (DIE, 2000). The present settled population is about one million capita. This population doubles in summer due to tourist influxes to the city. The high levels of both settled population and seasonal tourist influxes have some undesirable effects on the water and land resources, and the infrastructure of the city. Planning, designing, and operating a proper sanitation (collection, treatment and disposal) system have been a real challenge for the proper management of the water and soil resources of Antalya, and for a healthy and sustainable metropolitan life and tourism.

Groundwater is the main water supply source both for Antalya city and for irrigation. There are several drinking water wells and springs that lie within the residential area limits of the city or near to the agricultural areas. These wells were under the threat of several pollution sources before a challenging pollution control program were initiated. Figure 1 depicts the locations of the important groundwater wells in Antalya city.


***Figure 1**. Locations of the important groundwater wells*

The major threats to the groundwater resources of Antalya were the wastewater of the residential units and the existing little industries that were connected to holes or cesspits for their discharges. These holes and cesspits allowed the wastewater to percolate downwards through cracks in the underlying soil strata over several years since Antalya used to lack a proper sanitation system until recently. These cracks are connected to the groundwater reservoir and they are common in the karstic soil formation of Antalya. The soil structure below Antalya city has a very limited self-purification capacity. The filtration and ion exchange capacities, retardation factors for orthophosphate and other geo-hydrological properties of Antalya travertine plateau soil zone have been studied to examine the level of natural protection to the aquifer in a recent research. Soils especially around the main groundwater resources are classified to have low protective covers with low retardation factors, low soil thickness and shallow groundwater levels. The thickness of the vadose zone is below 50 meters which causes the physical, chemical and biological changes of the contaminants to occur within a relatively short period which further increases the risk of contamination from the residential areas (Basal and Ekmekci, 2000). The second major source of pollution was intensive green-house type agricultural activities that have shown a rapid increase in recent years in some areas adjacent to the city. The general trend among the farmers is to apply excessive amounts of chemical and organic fertilizers and pesticides that reached ultimately to these groundwater reservoirs. Since the groundwater flow is towards the sea, the near-field seawater was also under the pollution risk of wastewater and agrochemicals.

Since the soil did not provide adequate natural buffer zone and acceptable purification levels and Antalya did not have a proper sanitation system, some major water pollution parameters such as nitrate and coliform bacteria have shown an increasing trend in some wells during recent years. Figure 2 shows the trend of nitrate increase in these wells between 1989 and 1999 (Ates, 2002) while Table 1 gives the mean values and the ranges of total coliform values observed over the years from 1989 to 1999 (Ates, 2002). It is worth to mention that the nitrate concentrations in many wells such as the "Magara" well, which lies near to a crowded inhabitant area, and the "Topcular" well, which lies in an agricultural area, have exceeded the allowable limits stated by the Turkish Standards for drinking water purposes. As a result, these wells have been abandoned as public water supply sources (Tiryakioglu, 1999).

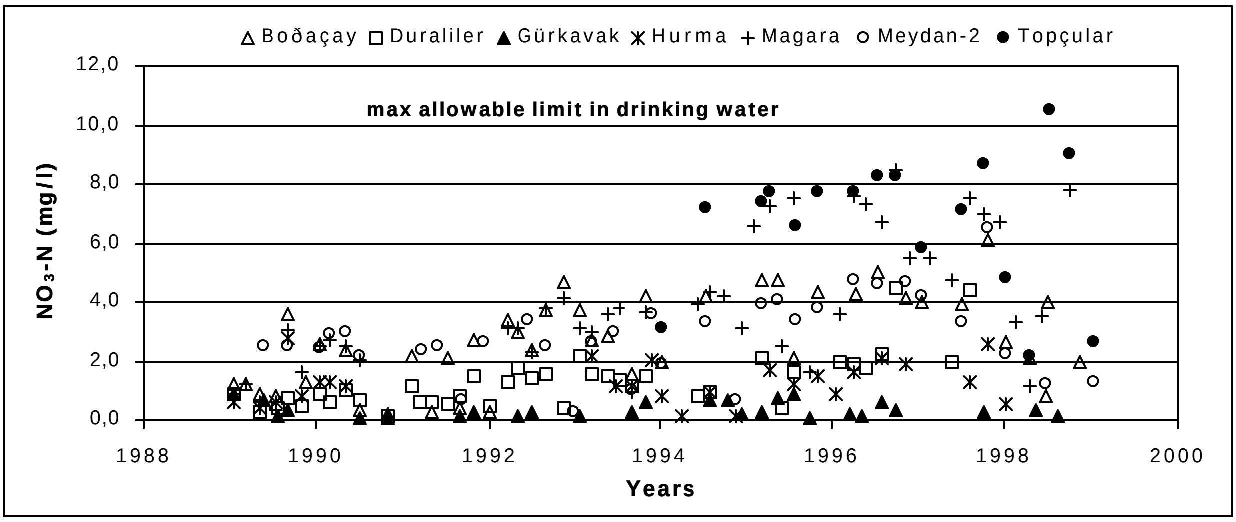



***Figure 2**. The trend of nitrate nitrogen concentration in groundwater resources*

**Table 1. The total coliform bacteria counts (per 100 ml) in the groundwater resources**

| Values | Bogaçay | Duraliler | Gürkavak | Hurma | Magara | Meydan-2 | Topcular |
|---|---|---|---|---|---|---|---|
| Mean | 8 | 58 | 205 | 84 | 8 | 13 | <1 |
| Range | 0-240 | 0-240 | 0-1000 | 0-500 | 0-240 | 0-240 | 0-1 |

Wastewater collection, treatment and disposal have become an urgent need for the protection of the groundwater resources of Antalya Plain, to stop the increasing trend of pollution. The final disposal of the treated effluents gains a special interest within the scope of overall sanitation project since prevention of sea pollution is essential while solving groundwater pollution due to diffuse sources in Antalya Plain. The paper discusses the characteristics of the water pollution control program of Antalya city with a special emphasis given on the final disposal method that employs a long and deep sea outfall system.

## METHODS

An integrated water and wastewater project has been initiated in the year 1996 to protect the drinking water resources and near field seawater quality. The project involved collection, treatment and disposal of the wastewater of the western part of Antalya city. Construction of new drinking water wells was within the scope of the project to replace the abandoned ones. The project was financed by Antalya Metropolitan Municipality, World Bank and European Investment Bank.

***Wastewater collection and treatment***

The total lengths already constructed of wastewater collection main pipes and house connections are about 650 km and 550 km respectively. The pipe diameters range from 0.2 m to 2.0 m. Concrete was the material for pipes of 0.2, 0.3, 0.4 and 0.5 m diameter, while reinforced concrete was used for the rest of the pipes. A total of five pumping stations were planned within the collection system. A preliminary wastewater treatment plant (WWTP), which includes screening, grit and grease removal has been planned initially for the treatment process. However, extended aeration activated sludge treatment units with nitrogen and phosphorous removal have been added after the public pressure for applying high level of treatment before any discharge to the sea environment.

***Wastewater disposal***

The treated wastewater is being discharged to Antalya Bay by a long and deep sea outfall, which was started to operate early 2001. The length of the main manifold of the sea outfall inside the sea is 2.6 km while the length of the diffuser section is 315 m. The average discharge depth of the wastewater is 48 m below sea level (Figure 3). The pipe material is high density-polyethylene (HDPE) and the outer diameter of the main manifold is 1.6 m. The nominal pressure rating of the pipe is 4 bar (PN4). The diffuser section consists of three parts each of 105 m length. The diameter of the first (upstream) part is kept as the diameter of the main manifold while the outer diameters of the second and third parts have been chosen as 1.2 m and 0.8 m respectively. The total number of ports is 120 and the diameter of each port is 0.16 m. Only 40 ports are open at this time while the other eighty ports will be opened in the coming years when the wastewater flow will increase. The minimum flow rate of wastewater is estimated as 280 l/s while the maximum flow rate is estimated as 4040 l/s (Muhammetoglu and Abdalla, 1999).

***Seawater quality monitoring*.**

A seasonal seawater quality-monitoring program has been initiated in late 1998 to assess the impact of the sea outfall on the quality of the seawater (Muhammetoglu *et al.*, 2003). The sampling and measurements program covered the years 1999 through 2002. Five s*hore* stations namely S1 through S5 were established close to the shore zone allocated for swimming and recreational activities. Also, five *offshore* stations namely U1 through U5 were also established. These stations have different depths and they are located at several directions around the discharge point of the sea outfall (Figure 3).

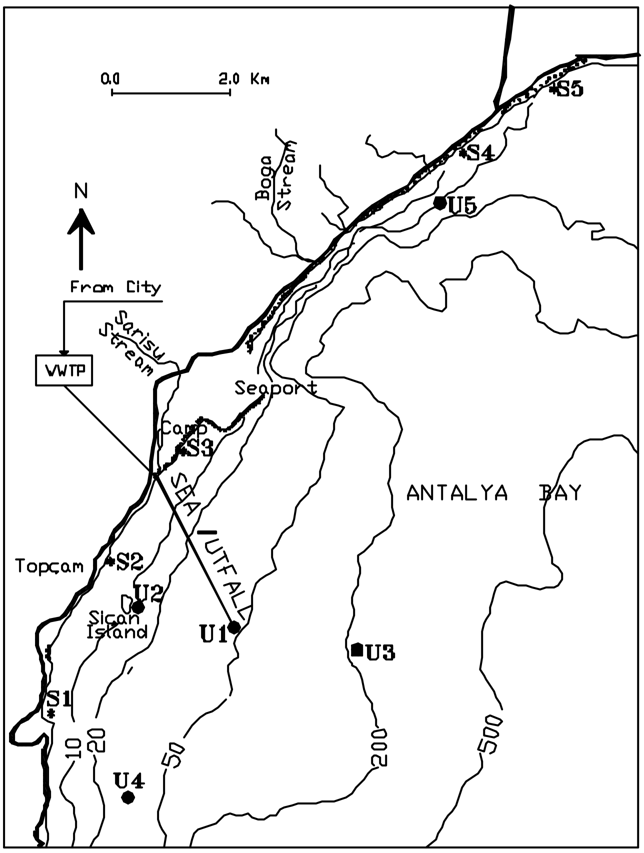



***Figure 3.*** *Locations of* shore *and* offshore *stations*

*In-situ* measurements of conductivity, salinity, temperature, dissolved oxygen (DO) and DO % saturation were carried out at each *offshore* station with a maximum depth interval of 5 m. Secchi depth measurements indicated seawater transparency at each station. Density values were calculated using temperature and salinity measurements (Riley and Skirrow, 1975). Water samples were collected from the surface, mid-depth and bottom at each *offshore* station and analyzed for parameters such as total suspended solids, 5-day biochemical oxygen demand, nitrogen and phosphorus compounds, and total and fecal coliforms. One representative depth-average seawater sample was collected from each *shore* station and analyzed for total and fecal coliforms.

***Adopted dilution estimation methods***

The discharged effluents from the sea outfall are subject to (i) initial or near field dilution, and (ii) far field dilutions that include dilution due to dispersion and dilution due to bacterial inactivation. Initial dilution was estimated using the work of Roberts *et al*. (1989). Dilution due to dispersion was estimated using the equations developed by Brooks (1960). The first order bacterial decay was considered for the third dilution. Total dilution was assumed to be equal to the multiplication of the three dilutions.

## RESULTS AND DISCUSSION

***Dilution of the discharged effluents***

The results of the monitoring program yielded reliable data for the quantification of the parameters needed for the dilution estimations and enabled some comparison between the predictions and field measurements.

Initial dilution.

The seasonal vertical density profiles have been produced using the measurements of the temperature and salinity depth profiles during the monitoring period. Thus, an average seasonal value for the vertical density gradient of seawater was calculated which is vital for the initial dilution calculations. The average density of seawater at the discharge level, which is 48 m below seawater surface, was calculated from the results of the measurements, as well. The density of the discharged wastewater was accepted as 1000 $kg/m^3$. Measured and projected flow rates were utilized for the dilution calculations. The basic design parameters and the results of the initial dilution are given in Table 2 and in Table 3 respectively. It is worth to mention that the discharged effluent is expected to be trapped below the seawater surface under the prevailing conditions. Moreover, the initial dilution and depth of wastefield submergence should exhibit high seasonal variations. The measured current velocities were too low to affect the values of initial dilution.

**Table 2. The prevailing magnitudes of the basic design parameters for the initial dilution calculations**

| Parameter | Year 2002 | | Year 2020 | |
|---|---|---|---|---|
| | Winter | Summer | Winter | Summer |
| Design flow rate (l/s) | 434 | 701 | 2500 | 4040 |
| Vertical density gradient of seawater ($kg/m^3.m$) | 0.01 | 0.05 | 0.01 | 0.05 |
| Density of seawater at the discharge level ($kg/m^3$) | 1028.5 | 1027.4 | 1028.5 | 1027.4 |
| Density of wastewater ($kg/m^3$) | 1000 | 1000 | 1000 | 1000 |

**Table 3. Calculated initial dilutions and depths of submergence below seawater surface**

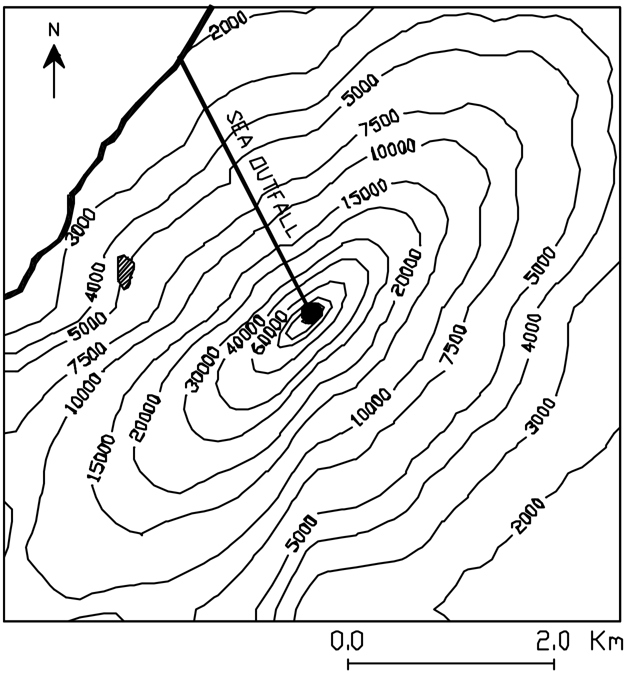
| Parameter | Year 2002 | | Year 2020 | |
|---|---|---|---|---|
| | Winter | Summer | Winter | Summer |
| Initial dilution | 255.5 | 89.6 | 205.5 | 72.1 |
| Depth of submergence (m) | 28.0 | 34.8 | 13.5 | 31.5 |

Dilution due to dispersion.

The sea current speed and direction at the depth of submergence are important parameters for the quantification of the dilution due to dispersion. These parameters have been recently measured at different depths near the sea outfall location continuously for two months with a time interval of 20-minutes using DCM 12 Doppler Current Meter in Mooring Frame 3438. The records were processed and the results were summarized as current roses (Muhammetoglu and Abdalla, 1999). It was realized that the sea current velocities reduce dramatically below the seawater surface that was indicated to be an important issue for the submerged effluents.

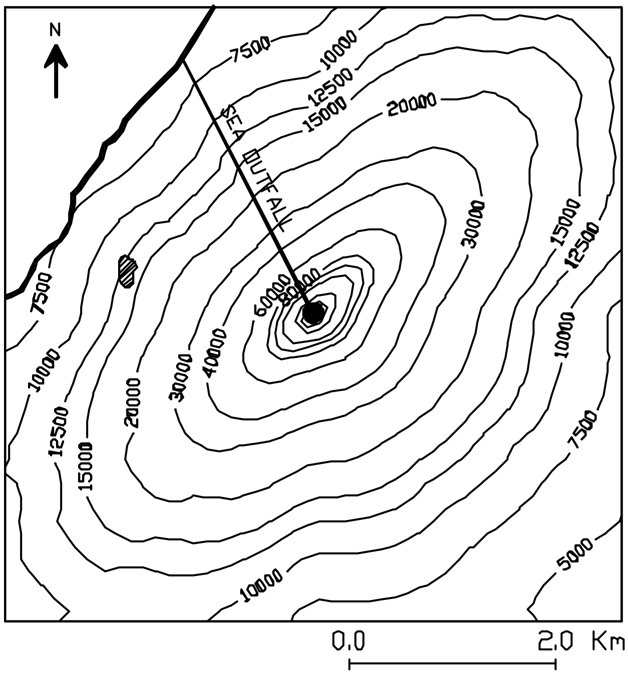
Dilution due to bacterial inactivation.

Rate of bacterial inactivation or the so called $T_{90}$, which is the time required for inactivation of 90% of the coliform bacteria, depends mainly on the degree of solar radiation. Bacterial inactivation below the surface or in the dark is a slow process, with $T_{90}$ values being in the order of days or even weeks (Gameson, 1986). The measurements in Marmara Sea of Turkey have shown that $T_{90}$ value in the dark was nearly forty times higher than the value on the surface during the summer season (Yükselen *et al*., 1995). In this specific study, the magnitude of $T_{90}$ was assumed as 45 hours that can be accepted as a reasonable value under dark environmental conditions (Yükselen *et al*., 1995). The selection of such a high $T_{90}$ value can be justified by comparing the magnitudes of Secchi transparency and the depths of submergence for Antalya Bay. The average Secchi depths in winter and summer were found as 4.80 m and 16.5 m respectively. A comparison of these values with the depths of submergence given in Table 3 reveals that the discharged wastewater will always remain submerged in the dark.



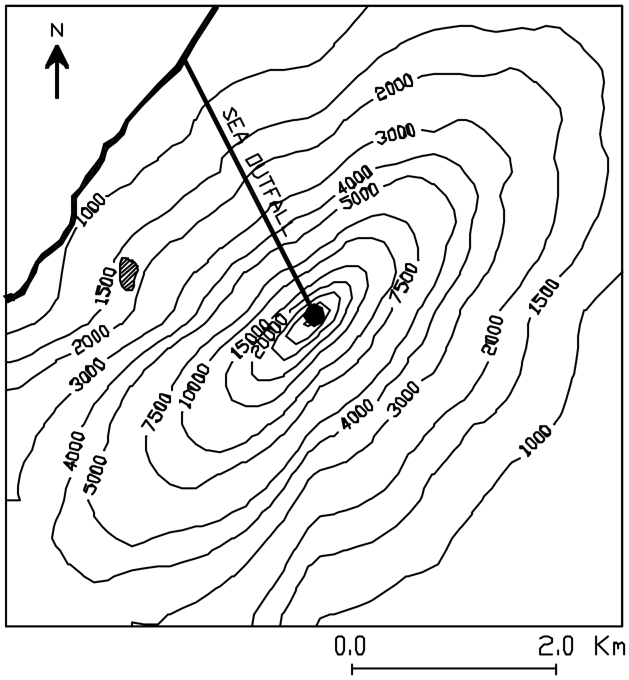

(a)

Initial dilution: 89.6
Submerged depth below surface: 34.8 m



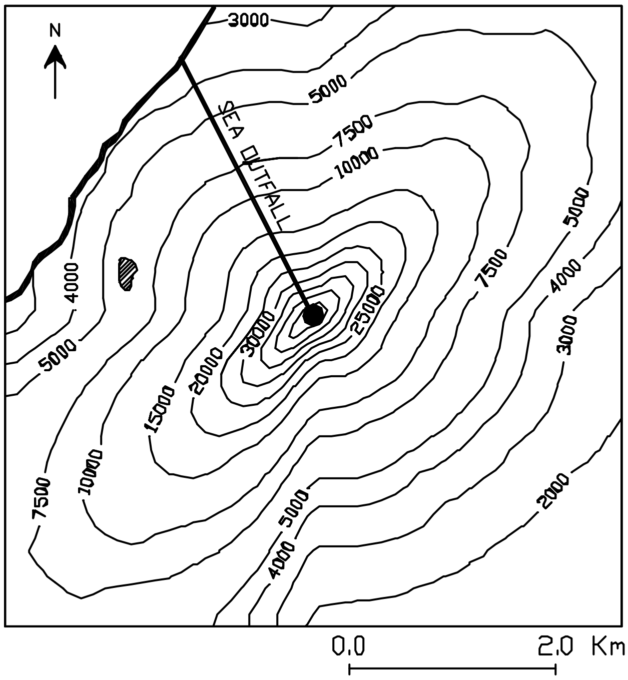

(b)

Initial dilution: 72.1
Submerged depth below surface: 31.5 m




(c)

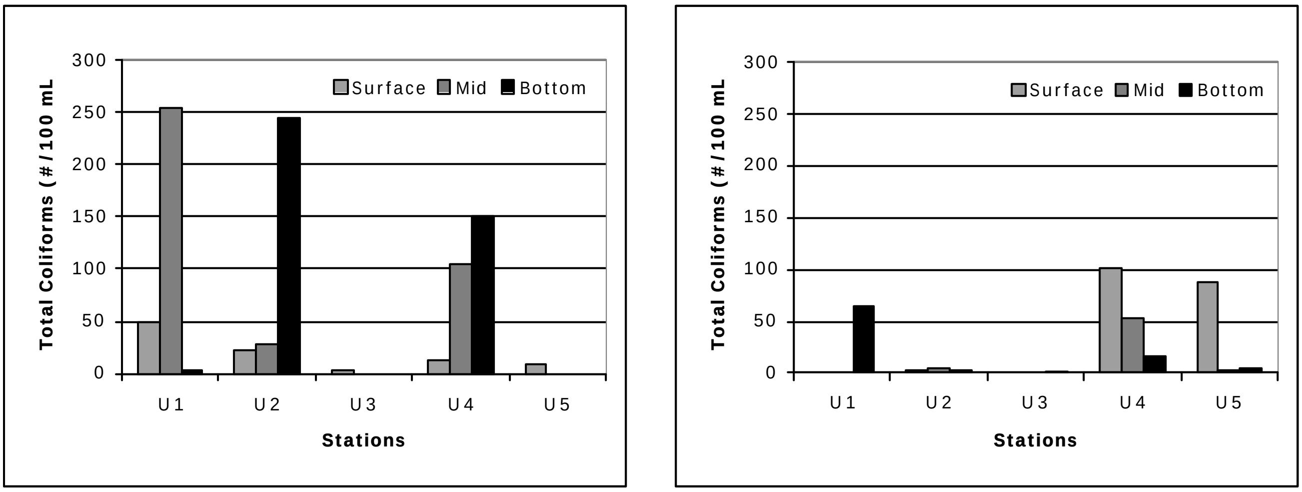
Initial dilution: 255.5
Submerged depth below surface: 28.0 m




(d)

Initial dilution: 205.5
Submerged depth below surface: 13.5 m

***Figure 4.*** *The contour lines for total coliform numbers per 100 ml in the considered conditions: (a) Year 2002, summer; (b) Year 2020, summer; (c) Year 2002, winter; (d)Year 2020, winter.*




(a) Winter (b) Summer

***Figure 5***. *Results of total coliform analyses in the* offshore *stations in 2002*

***Diffused pollutant concentration around the sea outfall***

Conservative pollutants are subject only to initial dilution and dilution due to dispersion while non-conservative pollutants are subject to initial dilution, dilution due to dispersion and dilution due to decay. In this study, the expected numbers of total coliform bacteria within the vicinity of the discharge point are calculated for summer and winter as an example. The total coliform bacteria in the discharged treated effluents of Antalya city was assumed to be in the order of $10^7$/100 ml considering the degree of treatment before discharge (Wastewater Engineering, 1991). The expected total dilution levels at several points that are at different distances and directions from the discharge point of the sea outfall were calculated from the results of the initial dilution, dilution due to dispersion and dilution due to bacterial inactivation as previously illustrated. Consequently, the expected total coliform counts were computed. The results are illustrated as contour lines for the expected total coliform counts (Figure 4). The figure indicates that the calculated numbers of expected total coliform levels have wide spatial and temporal variations.

The discharged wastewater is expected to submerge under all conditions and it is accepted that it will move horizontally at the depth of submergence. The wastefield will be trapped at the sea bottom in the shallow areas and it will not reach the shoreline. However, it may reach to the surface deteriorating the seawater quality if the density stratification is not stable or the depth of submergence is low. The purpose of the monitoring program around the sea outfall was not to verify the results of the dilution calculations, which is a procedure usually accomplished by dye tracer tests together with simultaneous measurements of different parameters such as current velocities, temperatures and salinities of seawater. Nevertheless, the expected submergence of the discharged effluents is supported by the monitoring program which indicated low total coliform and nearly no fecal coliform bacteria counts at the surface of the seawater at all the stations including the station located at the discharge point. Conversely, high numbers of total and fecal coliform bacteria have been detected from time to time at the samples extracted from the mid depth and bottom of the *offshore* stations (Figure 5). The measured total coliform concentrations comply well with the Turkish bathing standards of 1000/100 ml for 90% of the time.

## CONCLUSIONS

The planned, designed and constructed components of *Antalya Metropolitan, Water and Wastewater Project* has been completed recently and now the system components are being operated. The entire system has been conceptually designed to provide satisfactory collection of diffused sources of pollution over the valuable groundwater resources of Antalya Plain with subsequent treatment and disposal facilities to ensure controlled and acceptable levels of impact to the near field sea environment. The analysis presented by this paper showed that the designed system ensures an adequate recreational water quality with respect to bacteriological indicators of pollution along the shoreline allocated for recreational activities. However, it is highly recommended that the monitoring activities should continue to protect public health during recreational activities at the beaches of Antalya.

## REFERENCES

Ates S. (2002) *A Time Series Application on Groundwater Pollution for Antalya Province.* M.Sc. thesis, State Statistics Institute, Ankara, Turkey. (in Turkish).

Basal A. and Ekmekci M. (2000) "Natural attenuation characteristics of the Antalya Travertine Plateau soil zone as a protective cover for the aquifer", *Bulletin of Earth Sciences Application and Research Center of Hacettepe University*, vol. 22, 95-107 (in Turkish).

Brooks N. H. (1960) "Diffusion of Sewage Effluent in an Ocean Current", *Proc. 1st Intl. Conf. Waste Disposal in Marine Environment*, Pergamon Press, New York, NY, 246-268.

DIE (2000), *Turkish Yearly Statistics*. State Statistics Institute, Ankara, Turkey.

Gameson A.L.H. (1986), Bacterial mortality, Part 3, In *Investigations of Sewage Discharges to Some British Coastal Waters*, Chapter 8, WRc Technical Report TR 239, Medmenham, U.K., 74p.

Muhammetoglu A., Muhammetoglu H., Topkaya B. (2003) "Monitoring and Assessment of Seawater Quality around Antalya Sea Outfall", *Fresenius Environmental Bulletin*, 12 (7), (in press).

Muhammetoglu H. and Abdalla S. (1999). Antalya Sea Outfall and its Environmental Impact, *MEDCOAST 99 – EMECS 99 Joint Conference, Land-Ocean Interactions: Managing Coastal Ecosystems*, Nov. 9–13, 1999; Antalya, Turkey, pp. 1437-1448.

Riley J.P. and Skirrow G. (1975) *Chemical Oceanography*. Vol 1, 606 pp., Academic Press, London.

Roberts J.W.P., Synder W.H. and Baumgartner D.J. (1989). Ocean Outfalls. Parts: I, II and III, *ASCE Journal of Hydraulic Engineering*, Vol. 115, No.1, pp.1-25, 26-48, 49-70

Tiryakioglu O. (1999) *Graphic based evaluation of groundwater quality in Antalya and application of a mathematical model for pollution control*. M.Sc. thesis, Department of Environmental Engineering, Akdeniz University, Antalya, Turkey. (in Turkish).

*Wastewater Engineering: Treatment, Disposal, Reuse* (1991). 3rd edn, Metcalf & Eddy, Inc., ISBN 0-07-100824-1, International Edition.

Yükselen M.A., Kerc A. and Saatci A.M. (1995). Effect of solar intensity on bacterial die-off, *MEDCOAST '95 Conference, Proceedings of the 2nd International Conference on the Mediterranean Coastal Environment*, Oct. 24-27, 1995; Tarragona, Spain, pp. 1579-1585.