35th WEDC International Conference, Loughborough, UK, 2011

THE FUTURE OF WATER, SANITATION AND HYGIENE:
INNOVATION, ADAPTATION AND ENGAGEMENT IN A CHANGING WORLD

A sustainable method of effluent disposal: case study of Antalya Sea Outfall-Turkey

A. Muhammetoglu, O. B. Yalcin, T. Ozcan, L. Balas & C. Balas, Turkey

REFEREED PAPER 1183

Antalya city, located along the Turkish Mediterranean coast, lacked a proper sanitation system till 1996. An integrated water & wastewater project has been implemented to protect groundwater resources used for drinking and seawater quality. The project involved collection, treatment and final disposal of effluents by a deep sea outfall system. A current research project has been realized to evaluate performance of Antalya Sea Outfall. Seasonal in-situ measurements and bacteriological monitoring studies have been realized. The discharged wastewater plume is observed to be submerged in summer and to reach sea surface in winter condition. The results of the monitoring program exhibit considerable spatial and temporal variations. The resultant total and fecal coliform numbers comply well with the Turkish Standards for the use of coastal and sea water for recreation.

Introduction

The discharge of wastewater effluents to the marine environment, by means of marine outfall systems, represents a viable alternative for the populated coastal cities of the world. Such systems when properly designed, constructed and operated, can make maximum utilization of the natural assimilating capacity of the marine environment and do not cause an undesirable impact. The possible impacts of wastewater discharges can be listed as public health effects, aesthetic effects and effects on marine ecology (Ludwig, 1988). The public health concern, regarding the bacteriological requirements in bathing waters, is based on the prevention of contact between human and pathogenic organisms which might be present in the discharged effluents. Public health considerations are of even greater importance in coastal waters from which shellfish are harvested. Aesthetic concern relates to the possible presence of sewage associated materials such as floatable solids, grease and oil. Ecological effects include impact of sewage related substances on all types of marine organisms including possible substances such as chlorinated hydrocarbons and metals. The discharge of nutrients enriches the environment for phytoplankton growth where the discharge of particulate material covers the benthic layer and affects the benthic life. Due to these concerns, planning and design of a sewage effluent outfall system requires special attention (Ludwig, 1988). Additionally type of treatment applied before discharge of effluents to the marine environment has a great impact on the relative risk levels. Table 1 presents the relative risk potential to human health through exposure to sewage through marine outfall systems for different treatment stages and outfall types (WHO, 2003).

The functional design of a marine disposal system involves determination of the length of the outfall, the corresponding discharge depth, the length and orientation of the diffuser section, the specific hydraulic design of the pipeline and diffuser including shape, number, size and spacing of orifices. A proper design includes a combination of initial dilution, subsequent horizontal dispersion of the initially formed discharge plume due to sea current and bacterial inactivation sufficient to reduce coliform concentration from its initial value to a final value satisfying the standard for the protection of all beneficial uses (Salas, 2000). It is extremely valuable to carry out comprehensive field studies to collect data on currents, T_{90} (time required to inactivate 90% of the coliform bacteria), water quality, meteorology, bathymetry and geology prior to the outfall design. This paper aims to present a systematic approach to evaluate performance of sea outfalls using field data and monitoring results. The temporal and spatial variations of bacteriological water quality is presented for the case study of Antalya Sea Outfall System and compared with the recreational water quality standards.

Table 1. Relative risk potential to human health through exposure to sewage through outfalls (including stormwater runoff and combined sewer overflows) (WHO, 2003)

	Discharge type		
Treatment	*Directly on beach*	*Short outfall* [a]	*Effective outfall* [b]
None [c]	Very high	High	Not Applicable
Preliminary	Very high	High	Low
Primary (including septic tanks)	Very high	High	Low
Secondary	High	High	Low
Secondary plus disinfection [d]	---	---	---
Tertiary	Moderate	Moderate	Very low
Tertiary plus disinfection [d]	---	---	---
Lagoons	High	High	Low

[a]: The relative risk is increased for discharges from large populations and the sewage polluted water is likely to contaminate the recreational water area.
[b]: This assumes that the design capacity has not been exceeded and the extreme conditions are considered in the design objective.
[c]: Includes combined sewer overflows if active during the bathing season.
[d]: Additional investigations recommended to account for the likely lack of prediction with fecal index organisms.

Materials and methods

Antalya City is an important tourism center along the Turkish Mediterranean coast. Until recent years, the city faced the lack of a wastewater collection, treatment and disposal system. An integrated water and wastewater project has been initiated in the year 1996 to protect the drinking water resources and the sea environment. The construction of the new wastewater collection system and the treatment plant has been finalized in 2001. The collected wastewater is treated biologically in an extended aeration activated sludge treatment plant with nitrogen and phosphorus removal. The treated wastewater is being discharged to Antalya Bay by a long and deep sea outfall which was started to operate early 2001. The domestic wastewater from the west side of Antalya City is collected by a rather new wastewater collection system and treated in an advanced level at Hurma Wastewater Treatment Plant (WWTP). The treatment plant discharges about 1 m^3/s wastewater from the outfall system located 2600 m offshore in Antalya Bay which has an approximate discharge depth of 48 m. Diffuser system has a total length of 315 m and consists of three different parts with descending diameters of 1600 mm, 1200 mm and 800 mm respectively. Each diffuser part has 40 ports with equal diameters of 160 mm. An initial field survey study has been realized prior to the construction of Antalya Sea Outfall system to collect the required data and information before the design. Later on, a seawater quality monitoring program has been initiated to assess the impact of the sea outfall on the quality of the sea water. The details of the field surveys and the use of field data in the design procedure are described in the related references (Muhammetoglu *et al.*, 2003). A current research project has been carried out to evaluate performance of Antalya Sea Outfall system with field studies of in-situ measurements and bacteriological monitoring.

In-situ measurements

Seasonal in-situ measurements of temperature, salinity and conductivity were conducted along the water column with 5 m depth intervals at five stations around the diffuser section using WTW SCT Meter LF 197/LF 597 to observe temporal variations of the ambient environment (Figure 1). Density values were calculated using temperature and salinity measurements (Riley and Skirrow, 1975). The depth profiles of temperature and salinity are important design parameters of outfall systems. Both temperature and salinity stratification may lead to density stratification and submergence of waste plume. Secchi depth measurements were also conducted at each station to observe penetration of solar radiation along the water column. Additionally current velocity measurements were conducted near the diffuser section along the water column using an ultrasonic aquadoppler and floats.

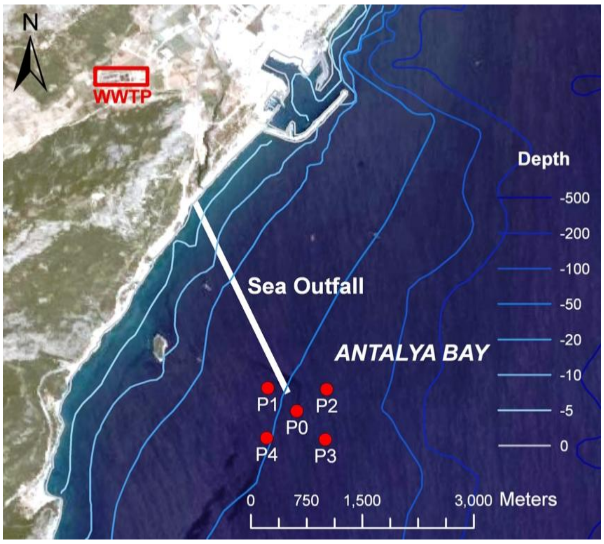

Figure 1. Location of Antalya Hurma Wastewater Treatment Plant (WWTP), sea outfall system and in-situ measurement stations

Bacteriological sampling

An intensive bacteriological monitoring study has been conducted at 24 stations established around the outfall system (Figure 2). The coordinates of all the sampling stations were recorded by a GPS that was used to find their positions during sampling studies. The sampling studies were performed along the water column with a depth interval of 5 m at all stations in February and July 2009 to represent winter and summer seasons. The sampling studies were conducted in the same week of in-situ measurements. The water samples were collected using two samplers (Hydro-Bios) and transferred into sterile glass bottles. The collected samples were transported from the sampling site to the laboratory within 4 hours and immediately analyzed for total coliform (TC) and fecal coliform (FC). Total and faecal coliforms were selected as target indicator organisms as they are present in the faeces of humans/warm-blooded animals and found in high concentrations in the discharged effluent (Yang *et al.*,2000, Gabutti *et al.*, 2000). Membrane filtration technique was applied for enumeration of bacterial groups. All laboratory analyses were conducted in duplicate. The samples were initially filtered through 0.45 µm sterile filter paper. The filter papers were placed in petri dishes having Endo type nutrient pads and incubated 24 hours at 36°C for TC analysis. Additionally mFC type nutrient pads and petri dishes were used to enumerate FC and incubated 24 hours at 44.5°C. Following the incubation period, coliform colonies that were developed on the filter papers were counted.

Determination of wastewater effluent characteristics

The daily flow rate of the discharged effluent from Hurma WWTP was obtained for the years 2008 and 2009. Additionally, TC and FC concentrations of the effluent were weekly sampled and analyzed for one year to determine temporal variations of the indicator bacteria. The samples were collected from the discharge unit of Hurma WWTP as grab samples and immediately taken to the laboratory for the analyses. The analyses of TC and FC were performed using membrane filtration technique in two replicates for the same sample following the same analysis procedure as described before.

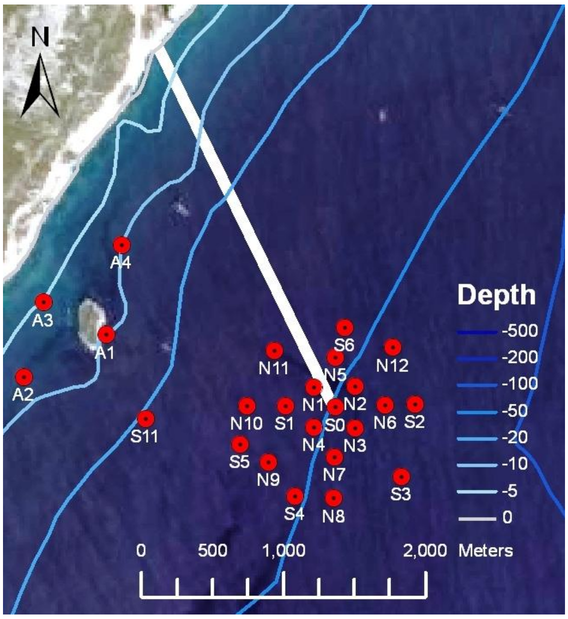

Figure 2. Locations of bacteriological sampling stations

Results and discussion

Wastewater effluent sampling

A total of 54 sessions of bacteriological analyses have been conducted for TC and FC, approximately once a week for one year period. The bacterial concentrations of the effluent were highly variable with distinct seasonal variations. The concentration of TC in the treated effluent was found almost 6.5 times of FC concentrations. The yearly averages of TC and FC concentrations in the effluent were determined as 5.10^5 and 8.10^4 cfu/100 ml respectively (Figure 3). Additionally, the daily flow rate of the discharged effluent was recorded by Antalya Water and Wastewater Administration. The yearly average flow rate of the discharged effluent was approximately 1 m^3/s.

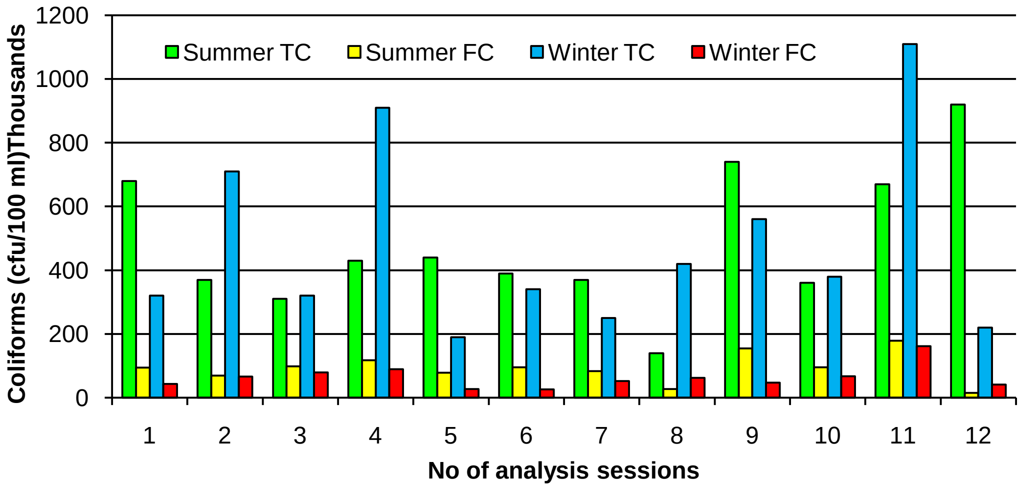

Figure 3. Bacteriological monitoring results of Hurma Wastewater Treatment Plant effluents

Field measurements

Seasonal field measurements of temperature, salinity and conductivity were conducted at the selected locations between August 2008 and July 2009. Depth profiles of temperature and density values are presented in Figures 4 and 5 for P0 station which is located at the end of the diffuser section of the outfall pipe. In fall, winter and spring seasons, rather uniform temperature profiles have been observed along the sampling depth of 50 meters being 24 °C, 16 °C and 20 °C respectively. In summer season, temperature was observed to gradually decrease from 28 °C to 24°C within the same depth. In winter and spring, lower salinity values were measured at sea surface due to freshwater inputs from incoming streams and rain water.

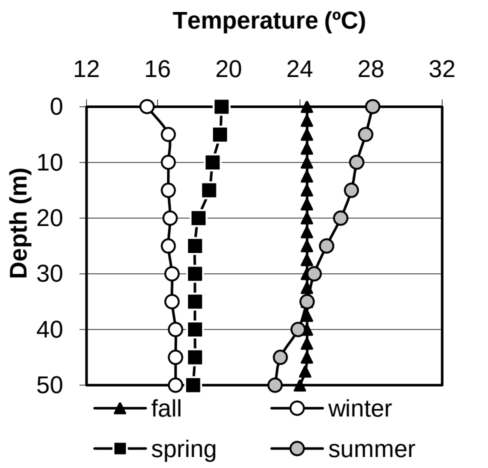

Figure 4. Seasonal depth profile of temperature at station P0

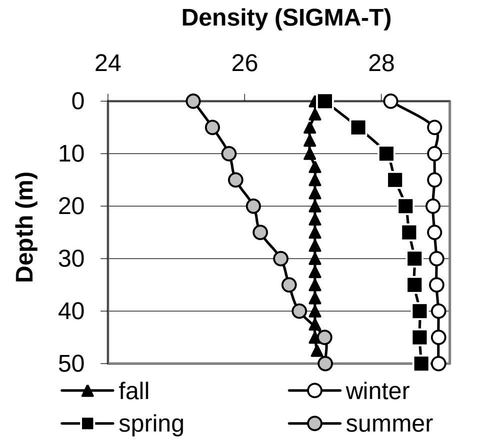

Figure 5. Seasonal depth profile of density at station P0

A rather uniform density profile was observed in fall season whereas a distinct linear increase of density was observed in summer. In winter and spring, density values were low at sea surface and a gradual increase was observed up to 5 m in winter and 20 m in spring whereas uniform density values were dominant below these depths. In terms of density, a rather completely mixed ambient condition was observed in fall and winter seasons up to 50 m. A slight thermal stratification was observed in spring and it becomes more distinct in summer which leads to strong density stratification. Current measurements conducted in winter and summer are presented in Figures 6 and 7 where the dominant directions were towards south. Current measurements are required to compute dilution levels of discharged effluents.

Sampling results of indicator microorganisms

Observed TC and FC concentrations are presented in Tables 2 and 3 for winter and summer seasons at some of the sampling stations with high bacteriological pollution. The presented data shows spatial and temporal variations of bacteriological pollution. In winter season high coliform concentrations were observed along the whole sampling depth which indicates surfacing of wastewater plume. In summer season, there are nearly no coliforms from surface to 20 m depth and high concentrations of coliforms are observed between 25 m to 40 m. This phenomenon is due to submergence of wastewater plume.

Bacteriological standards

There are many studies on the application of microbiological water quality standards in marine environment for primary contact recreation. According to the research studies conducted in the U.S.A., enterococci, as an indicator organism, provided the best correlation with gastrointestinal symptoms attributed to swimming in contaminated waters. U.S. Environmental Protection Agency adapted enterococcus as the primary indicator organism as presented in Table 4 (USEPA, 1986). Similarly, the World Health Organization (WHO) has presented Guidelines for Safe-Recreational-Water-Environments in 1998 using fecal streptococcus as the indicator organism and later in the year 2003, Guideline Values for Microbial Quality of Recreational Waters were published using intestinal enterococci as the indicator organism (WHO, 2003), as presented in Table 5.

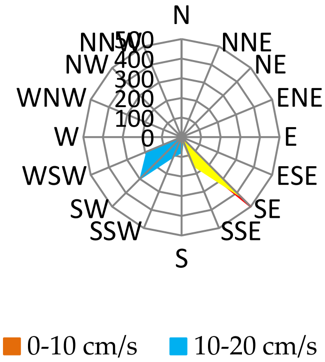

Figure 6. Current measurements in winter at surface

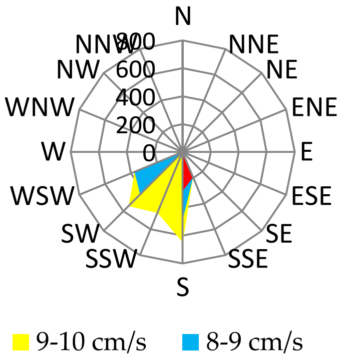

Figure 7. Current measurements in summer at 35-40 m depth

Table 2. Observed bacteriological pollution at some of the stations in winter season (TC: total coliform, FC: fecal coliform in cfu/100 ml units)

Station	S0		S6		N1		N2		N5		N12	
Depth	TC	FC	TC	FC	TC	FC	TC	FC	TC	FC	TC	FC
0	68	3	7	5	31	4	25	5	52	47	8	1
5	14	7	533	309	46	5	495	106	471	314	558	108
10	385	196	788	300	34	2	600	297	495	320	888	364
15	44	25	473	299	15	18	460	180	488	232	310	138
20	417	135	217	74	904	353	30	22	16	14	7	2
25	57	15	21	5	893	375	4	1	1	2	1	1
30	7	1	42	25	46	12	3	1	1	1	4	2
35	102	54	2	1	403	121	1	1	0	1	888	412
40	15	1	1	0	54	14	10	5	1	0	10	4
45	91	43	1	1	132	1	693	212	358	351	2	0

Table 3. Observed bacteriological pollution at some of the stations in summer season (TC: total coliform, FC: fecal coliform in cfu/100 ml units)

Station	S1		S5		N1		N2		N3		N10	
Depth	TC	FC	TC	FC	TC	FC	TC	FC	TC	FC	TC	FC
0	4	0	0	0	0	0	5	0	1	0	4	0
5	13	0	1	0	0	0	2	0	0	0	0	0
10	11	0	4	0	0	0	0	0	0	0	1	0
15	10	0	4	0	0	0	0	0	0	0	4	0
20	4	0	17	0	0	0	2	0	1	0	7	1
25	1	0	264	144	0	0	6	0	1	0	85	57
30	1	0	329	139	139	39	284	263	2	1	157	103
35	214	134	19	7	3	2	5	3	202	110	39	12
40	119	74			256	126	3	0	3	3		
45							2	1	0	1		
50							1	0	7	10		

The microbiological parameters of bathing water quality used in the European Union (Directive 2006/7/EC) are presented below in Table 6 for comparison. The Turkish Standards for the use of coastal and sea water for recreation include total and fecal coliform parameters for microbiological standards and some important ambient conditions of deep outfalls are presented in Table 7 (WPCR, 2008).

Table 4. US-EPA's recommended marine water quality criteria for bacteria (USEPA, 1986)

Indicator	Illness Rate (per 1000)	Geometric Mean Density	Single Sample Maximum Allowable Density			
			Designated Beach Area 75% C.L.*	Moderate Full Body Contact Recreation 82% C.L.	Lightly used Full Body Contact 90% C.L.	Infrequently Used Full Body Contact 95% C.L.
Enterococci	19	35	104	158	276	501

* Confidence level

Table 5. Guideline Values for Microbial Quality of Recreational Waters (WHO, 2003)

95^{th} percentile value of intestinal enterococci/100 ml	Basis of derivation	Estimated risk per exposure
≤40	This range is below the NOAEL in most epidemiological studies.	<1% GI illness risk <0.3% AFRI risk
41-200	200/100 ml value is above the threshold of illness transmission reported in most studies.	1 - 5% GI illness risk 0.3 – 1.9% AFRI risk
201-500	Represents a substantial elevation of all adverse health outcomes.	5- 10% GI illness risk 1.9 – 3.9% AFRI risk
>500	There may be significant risk of high levels of minor illness transmission.	>10% GI illness risk >3.9% AFRI risk

AFRI = acute febrile respiratory illness; GI = gastrointestinal;
NOAEL = no-observed-adverse-effect level.

Table 6. Microbiological parameters of bathing water quality in the European Union (Directive 2006/7/EC)¶

	A	B	C	D
	Parameter	Excellent quality	Good quality	Sufficient
1	Intestinal enterococci (cfu/100 ml)	100 (*)	200 (*)	185 (**)
2	Escherichia coli (cfu/100 ml)	250 (*)	500 (*)	500 (**)

(*) Based upon a 95-percentile evaluation. (**) Based upon a 90 percentile evaluation.
¶ Refer to the Directive for frequency of sampling and other details.

Table 7. Some important ambient conditions for deep sea outfalls in Turkey (WPCR, 2008)

Parameter	Limit
Temperature	The temperature of discharged water is not allowed to exceed 35 ˚C in any condition. For thermal discharges, it is not allowed to increase the seawater temperature by 1 ˚C in the summer period (from June to September) and by 2 ˚C in the other months after the initial/physical dilution process. In case of ambient seawater temperatures in excess of 28 ˚C, no criteria is applied for temperature of discharged water but the ambient seawater temperature is not allowed to increase more than 3 ˚C.
Total and fecal coliforms	The number of total coliform in the protection zone (with human contact) is restricted to be less than 1000 TC/100 ml and 200 FC/100, in 90% of the time, after total dilution processes achieved by deep sea outfall discharges.
Solid/floating substances	No solid and floating substances are allowed to be visible outside a path which is restricted in size to the depth of the outfall.
Other parameters	Specific criteria are defined for general seawater quality for pH, color and turbidity, floating substances, suspended solids, dissolved oxygen, biodegradable organics, crude oil and derivatives, radioactivity, seasonal productivity, phenols and heavy metals.

Additional guideline values of the wastewater characteristics eligible for deep sea outfall are pH (6-9), temperature (35 ˚C), suspended solids (350 mg/L), oil and grease (15 mg/L), 5-day biochemical oxygen demand (250 mg/L), chemical oxygen demand (400 mg/L), total nitrogen (40 mg/L), total phosphorus (10 mg/L) and some other hazardous parameters (WPCR, 2008). The limits and parameters of recreational water quality differ in developed and developing countries. The observed coliform concentrations around Antalya Sea Outfall comply with the Turkish Regulations of Bathing Water Quality Standards and the other guideline values of water quality parameters indicating good performance of the outfall.

Conclusion

The discharge of domestic wastewater through marine outfalls is commonly used to take advantage of extensive assimilation capacity of the sea environment. If these biodegradable effluents are adequately mixed and dispersed in the receiving environment, this application could be evaluated as a sustainable disposal option. In this application, particular emphasis has been given to evaluation of Antalya Sea Outfall system performance with intensive bacteriological sampling of coliform organisms. The conducted study for Antalya Sea Outfall system demonstrates that the discharged effluent may reach sea surface in winter season due to rather uniform density values along the water depth. In density stratified ambient conditions of summer, the waste plume is expected to be submerged at certain depth. The bacteriological monitoring results exhibit considerable spatial and temporal variations due to seasonal changes in ambient conditions.

Acknowledgements

This study has been supported by TUBİTAK with Project No: 107Y184 and Akdeniz University Research Projects Unit with Project No: 2008.01.0102.004 and 2009.02.0121.001.

References

Gabutti G., Donno A., Bagardo F., Montagna M. T. (2000) *Comparative Survival of Faecal and Human Contaminants and Use of Staphylococcus Aureus as an Effective Indicator of Human Pollution*, Marine Pollution Bulletin, 40: 8, 697-700.

Ludwig, R.G. (1988) *Environmental Impact Assessment, Siting and design of submarine outfalls*, University of London-Monitoring and Assessment Research Center and WHO, 67 pp.

Muhammetoglu, A., Muhammetoglu, H. and Topkaya, B. (2003) *Monitoring and Assessment of Seawater Quality Around Antalya Sea Outfal*, Fresenius Environmental Bulletin, Vol 12, No.7, pp. 718-723.

Riley J. P., Skirrow G. (1975) *Chemical Oceanography*, V. 2, 2nd Ed. Academic Press, New York and London, p. 647.

Salas, H.J. (2000) *Submarine Outfalls: A Viable Alternative For Sewage Discharge of Coastal Cities in Latin America and The Caribbean*, Pan American Center For Sanitary Engineering and Environmental Sciences,WHO, 21 pp.

US EPA (1986) *Ambient Water Quality Criteria for Bacteria*, Environmental Protection Agency, Office of Water, EPA 440/5-84-002, Washington DC. 22 pp.

WHO (2003) *Guidelines for Safe Recreational Water Environments*, Volume 1: Coastal and Fresh Waters, World Health Organization, Geneva.

WPCR (2008) Water Pollution Control Regulation, Turkish Republic Ministry of Forestry and Environment, published in Official Gazette; Date: 31.12.2004, No: 25687.

Yang L., Chang W., Huang M. L. (2000) *Natural Disinfection of Wastewater in Marine Outfall Fields*, Water Research, 34:3, 743-750.

Contact details

Ayse Muhammetoglu
Akdeniz University, Engineering Faculty
Tel: +90 242 310 63 28
Fax: +90 242 310 63 06
Email:aysemuh@akdeniz.edu.tr
www.akdeniz.edu.tr

Ozgur Bulent Yalcin
Akdeniz University, Engineering Faculty
Tel: +90 242 310 63 24
Fax: +90 242 310 63 06
Email:oby@akdeniz.edu.tr
www.akdeniz.edu.tr