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Operational Paper

The impact of watershed land use on maintaining acceptable quality influents for water treatment plants

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ABSTRACT

Providing acceptable quality water in sufficient quantities is a challenge that local authorities have to face in various parts of the world, especially for bigger cities and megacities where there is a rapidly increasing population and difficulties in the control of new housing and provision of proper infrastructure. The quality of water distributed is strongly dependent on the quality of water coming in to the water treatment plant from the water resource, which in turn is dependent on the conditions of its watershed. Better quality influents are expected of water resources with well-controlled watersheds in terms of population, population density, residential, industrial and agricultural activities and pertinent infrastructure to account for those activities. The Turkish megacity of Istanbul, which has been experiencing this pressure with apparent impacts of watershed land use on the water quality of its water supply reservoirs, provides a case to be considered for water management in the new century.

Key words | drinking water reservoirs, land use, population density, protection zones, watershed, water quality management

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INTRODUCTION

Good quality water service necessitates good quality water for distribution as one of the primary factors. Regardless of the type of treatment scheme used for supplying drinking water for public use, the performance of the plant is strongly dependent on the influent, the quality of which is dictated by the quality of the water resource itself. Communities relying on surface water resources for this purpose must exercise utmost care to keep their resources at an acceptable quality level. This, in turn, is closely related to the land use practice within the watersheds.

Within this context, a sound land use plan and its uncompromised implementation are prerequisites for control of pollutants impacting water resources at the source of pollution. A watershed which is limited in the degree of housing and in terms of industrial activities is more suitable as hinterland compared with one which has been experiencing intense urbanization especially in the form of intensive settlements and industries. This is an even more significant problem for megacities of the world, which are frequently under the stress of migrating population from other parts of the country. Especially at locations where either land use plans are not appropriate or supervisory/regulatory control is not sufficient within the context of the intended beneficial use of the water resources, watersheds seem to be vulnerable areas where new housing, generally illegal, appears.

Taking Istanbul as an example, a Turkish megacity of over 10 million inhabitants with about 50% of Turkish industry in its vicinity, over 90% of the water demand of about 1 billion $m^3\ yr^{-1}$ is abstracted from six surface water reservoirs. Control of land use in the watersheds of those reservoirs in accordance with the official land use

Journal of Water Supply: Research and Technology—AQUA | 52.8 | 2003

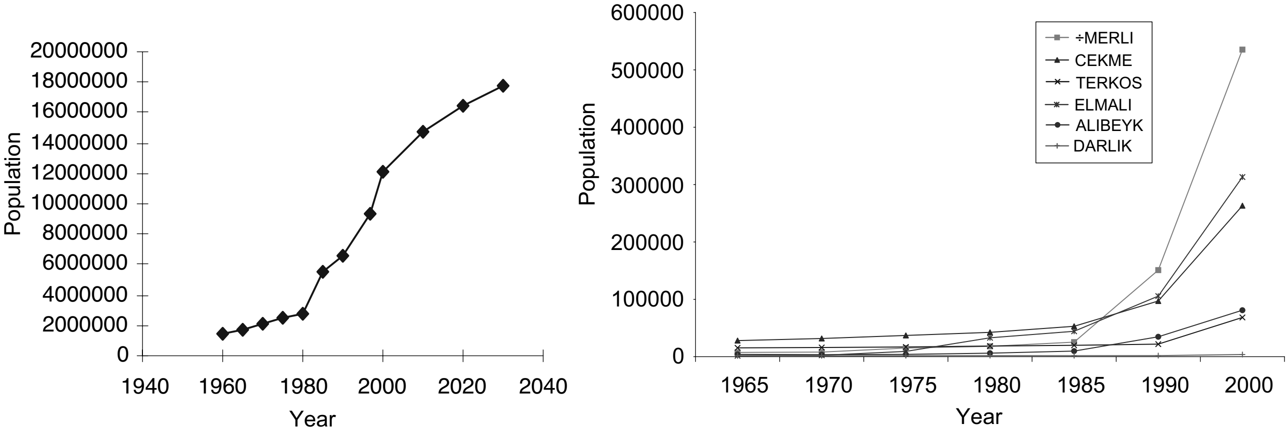

Figure 1 | Population changes in Istanbul and its watersheds.

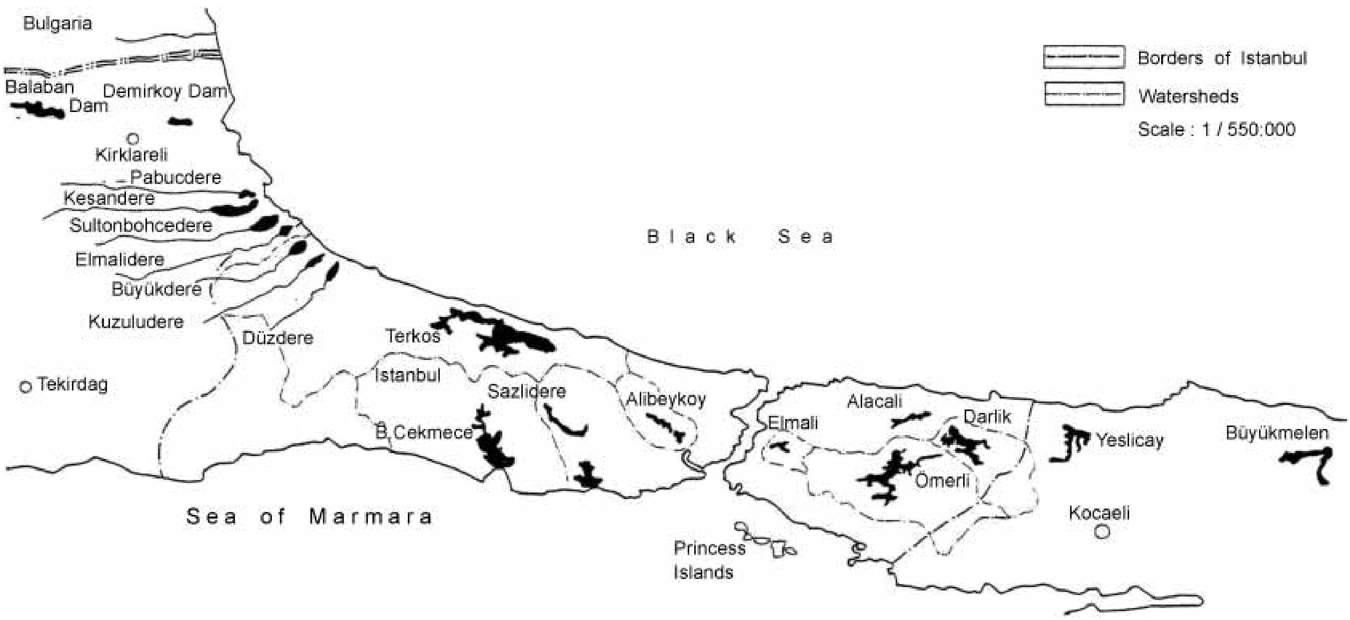

Figure 2 | Present and future water resources of Istanbul.

plans is a real challenge. Increasing population, mostly through migration, and intensive settlements, frequently in the form of illegal housing which lacks proper infrastructure, stress these water bodies.

This is not only an issue for Istanbul but also for other rapidly developing cities especially in the developing countries. The typical bottleneck in most megacities is rapid urbanization in the form of population increase and industrial development that lacks proper physical planning, pertinent infrastructure and relevant, timely measures to accommodate the rapid change. Local authorities of megacities work to find ways to meet water demands at acceptable quality, quantity and cost, which requires the formulation and implementation of sound, well-coordinated and integrated water resources management plans, which are to be handled in a holistic manner and prepared separately for each water resource. Recently, the management trend is changing to the 'integrated

Table 1 | The share of present water resources for water supply in Istanbul

Reservoir	Watershed area (km^2)	Reservoir area (km^2)	Annual water production (million m^3)	Share (%)
Omerli	621	23	220	36.0
Terkos	619	32	142	23.3
Buyuk Cekmece	621	36	100	16.4
Darlik	199	6	97	15.9
Alibeykoy	160	3	36	5.9
Elmali	81	4	15	2.5

watershed management' approach, which considers the watershed in addition to the water body, and is based on natural boundaries of watersheds rather than man-made boundaries of towns or municipalities.

The water demand of Istanbul increases parallel to its rapidly increasing population. In all six reservoirs of the metropolis, point sources from housing and industry dominate over non-point sources mainly because infrastructure is missing or is not meeting the increasing demand. Future plans are to supply water from distant resources by the end of the first quarter of the 21st century to meet the demand. However, if proper measures are not taken, Istanbul may have to resort to distant resources and will have to pump water from hundreds of kilometres from the city, sooner than expected.

This paper aims to discuss how Istanbul could be an example in the 21st century, within the framework of the need for control of settlements and industry by local administrations, with a 'no compromise' approach and sanctions as needed, together with timely, pertinent infrastructure, referring predominantly to populations, population densities, protection zones, land use and urban activities.

WATER RESOURCES OF ISTANBUL AND THEIR WATERSHEDS

Istanbul has a current population of over 10 million as shown in Figure 1 (ISKI 2000), and a population increase rate around 4.9% in recent years, about twice that of Turkey. Due to the immense migration it receives from all over the country every year, its population has been increasing in a manner that is hard to keep up with in terms of services including water supply. The water demand was estimated to be about 2,800,000 m^3 day^{-1} or 1,032,000,000 m^3 yr^{-1} in 2000 (ISKI 2000). Within this context, the local authorities, as well as the central government, have to face a vast challenge in providing acceptable quality services in sufficient quantities at a reasonable cost, while maintaining the sustainability of resources.

Table 2 | Land use distribution in the watershed of drinking water reservoirs of Istanbul

Land use	Omerli %	Terkos %	B.Cekmece %	Darlik %	Alibeykoy %*	Elmali %
Forests/Bushes	51	77	20	72	68	40
Agriculture/Meadows	35	17	63	24	19	30
Settlement/Industry	10	1	12	1	3	25
Lake	4	5	5	3	2	5
Total Area (km^2)	621	619	621	199	160	81

*The remaining percent goes to other uses such as mining and stone mining.

Table 3 | Settlements in the watersheds of drinking water reservoirs of Istanbul (Cetiner *et al*. 1994)

Watershed	Protection zone	Area (km^2)	%	No. of settlements	Population	%	Population density (persons km^{-2})
Omerli	Absolute	40	7	3	1,438	1	36
	Short	55	9	2	2,545	2	46
	Medium	63	10	4	963	1	15
	Long	440	74	17	145,964	96	332
	Total	598	100	26	150,910	100	252
							Overall
Terkos	Absolute	25	4	2	3,599	16	144
	Short	51	9	2	1,443	7	28
	Medium	62	11	3	927	4	15
	Long	449	76	14	15,926	73	35
	Total	587	100	21	21,895	100	37
							Overall
B.Cekmece	Absolute	19	3	3	2,697	4	142
	Short	34	6	1	12,240	16	360
	Medium	44	8	1	900	1	20
	Long	488	83	24	58,848	79	74
	Total	585	100	29	74,685	100	154
							Overall
Darlik	Absolute	11	9	—	—	—	0
	Short	17	9	—	—	—	0
	Medium	16	8	—	—	—	0
	Long	149	74	7	1,885	100	13
	Total	193	100	7	1,885	100	13
Alibeykoy	Absolute	12	8	1	3,699	11	308
	Short	18	11	—	—	—	0
	Medium	20	13	—	—	—	0

Journal of Water Supply: Research and Technology—AQUA | 52.8 | 2003

Table 3 | *Continued*

Watershed	Protection zone	Area (km^2)	%	No. of settlements	Population	%	Population density (persons km^{-2})
Alibeykoy cont'd	Long	107	68	5	31,007	89	293
	Total	157	100	6	34,706	100	221 Overall
Elmali	Absolute	10	14	1	4,693	4	469
	Short	12	16	—	—	—	0
	Medium	29	37	1	13,523	13	466
	Long	26	33	2	87,457	83	3,364
	Total	77	100	4	105,673	100	1,372 Overall

Over 90% of the demand is supplied from surface water, currently from six drinking water reservoirs of which three, Terkos, Buyuk Cekmece and Alibeykoy, are located on the European side and three, Omerli, Darlik and Elmali, on the Asian side, as shown in Figure 2. Table 1 shows the share of each water resource.

The main national regulation for water quality is the Water Pollution Control Regulation (WPCR) of the Turkish Republic of 1988. The local authority responsible for the drinking water services of Istanbul, Istanbul Water Works and Sewerage Administration (ISKI) uses mainly the same approach as WPCR with some minor amendments made in 1996. Protection zones are defined around the water reservoirs intended for water supply in WPCR as:

- Absolute Protection Zone: the band from the water surface to 300 m,
- Short Range Protection Zone: the band from 300 to 1,000 m,
- Medium Range Protection Zone: the band from 1,000 to 2,000 m,
- Long Range Protection Zone: the band from 2,000 m to the border of the watershed.

The activities permitted and prohibited in these zones along with some measures of pollution control are also described in WPCR. No permanent settlements and industrial activities in the absolute and short-range zones are permitted. Starting with the medium range protection zone, very low density single housing under special measures and constructional restrictions is permitted. No new industrial developments are to be permitted and the old ones are to be removed from the watershed as far as possible. However, if there is no possibility for this, they may be allowed to work in their current location under special precautions of pollution control and compliance with very stringent standards.

The 1996 revision of the ISKI regulation subdivides the long range protection zone further in two, to give two different settlement conditions, and permission for single settlements starting from the short range protection zones with very low population densities and under special conditions, with higher population densities in other zones, densities increasing stepwise from the short range to the long range zones.

Tables 2, 3 and 4 summarize the characteristics of land use, settlements, population densities and industries in the watersheds of the currently used drinking water

Table 4 | Industries in the watersheds of Istanbul (Gonenc *et al.* 1995a,b,c,d,e,f)

	Number of industries					
Watershed	Absolute	Short	Medium	Long	Total	Predominant sectors
Omerli	3	5	10	226	244	Metal industry (16%)
						Feedstock industry (15%)
Terkos	1	2	—	6	9	Feedstock industry (50%)
						Non-metallic mining & processing (13%)
B.Cekmece	16	23	13	77	129	Feedstock industry (44%)
						Non-metallic mining & processing (9%)
						Textile industry (8%)
Darlik	—	—	—	—	—	—
Alibeykoy	6	6	14	247	273	Plastics industry (15%)
						Metal industry (12%)
						Feedstock industry (11%)
						Non-metallic mining & processing (11%)
						Metal casting (10%)
Elmali	5	—	1	78	84	Metal industry (20%)
						Electrical/electronics ind. (7%)

reservoirs of Istanbul. As can be observed from Tables 3 and 4, there are already some settlements in the absolute and short range protection zones, and population densities are higher than those allowed at some locations in the medium and long range protection zones. Furthermore, in some cases, some settlements have come to exist in their respective locations without the provision of the formal land use plan, and most of them have insufficient infrastructure regarding wastewater services. In terms of industries, about one-fifth of the industry in the vicinity of Istanbul is actually located in the protection zones (Cetiner & Ciftci 1996), which contradicts WPCR.

Implementation of these restrictions and controls are the responsibility of ISKI and local administrations. It is obvious that success depends on strict control and a 'no compromise' approach by both institutions, both from the point of view of water quality control in the reservoirs, mostly by ISKI, and proper land use plan practice, mostly by the local administrations/municipalities.

Table 5 | Classification of the drinking water reservoirs of Istanbul according to the Technical Standards (Gonenc *et al.* 1995a,b,c,d,e,f; Beler Baykal 1997; Beler Baykal *et al.* 2000)

	Hydrographic and territorial criteria	Trophic criteria	Salinity, special criteria and hygienically relevant criteria	Overall evaluation
Omerli	2	3 (2.9)*	2	2 (2.3)
Terkos	2	3 (2.5)	3	2 (2.7)
B.Cekmece	3	2 (2.0)	3	3 (2.7)
Darlik	1	**	2	2 (1.5)
Alibeykoy	3	3 (2.5)	2	3 (2.7)
Elmali	3	4 (4.3)	3	3 (3.3)

* Numbers in parentheses indicate averages not rounded off.
** Not reported due to very limited data

THE PRESENT STATUS OF WATER QUALITY

The official water quality classification in Turkey is given by the WPCR. However, it is based only on the quality values that exist in the water body and does not provide versatile information for decision makers. Hence, the classification of the drinking water reservoirs of Istanbul used herein was made in accordance with the Technical Standards of East German origin which have the advantage of considering the lake as a part of the watershed by which it is impacted, in order to provide a holistic view needed especially in megacities. With this approach, the interaction between water quality and lake morphology together with the impact of the watershed are taken into account. Moreover, nutrients in the lake are investigated in detail together with the impact of external loads from the watershed on water quality, providing easily understandable and usable data for water quality management decision makers. Evaluation is made under three main groups of criteria that are subdivided further as:

- Hydrographic and territorial criteria: morphology, hydrographic relationship between drainage area and the lake, anthropogenic nutrient load;
- Trophic criteria: oxygen balance, nutrient budget, bioproduction;
- Salinity, special criteria and hygienically relevant criteria: salinity, special criteria, hygienically relevant criteria.

After evaluating the quality class for each group, the overall quality class is determined by taking the average of the three groups (Ryding & Rast 1989; Beler Baykal *et al.* 1996). According to this approach, first class water may be used as a drinking water supply following filtration and disinfection whereas second class water may be utilized after treatment in a typical water treatment scheme. Third class water is not suitable for this purpose and can only be used after complex treatment.

Table 5, presenting the classification of water quality in the drinking water supply reservoirs of Istanbul in accordance with Technical Standards, reveals that one of the six reservoirs, Darlik, is in a state of transition from the first class to the second class while one other, Elmali, has exceeded class three. As such, Elmali could not be used as a drinking water resource in accordance with WPCR and could only be used after complex treatment in accordance with the Technical Standards. Due to this fact, ISKI has launched action for the revision of the water treatment system serving Elmali. The other reservoirs, Omerli, Terkos, Buyuk Cekmece and Alibeykoy show second class characteristics tending to third class.

Journal of Water Supply: Research and Technology—AQUA | 52.8 | 2003

Table 6 | Ranking from the worst to the best in the drinking water reservoirs/watersheds of Istanbul (Beler Baykal 1997; Beler Baykal *et al.* 2000)

Population	Population density	Land Use, % of the total area devoted to settlements	Industry	Overall quality class	Trophic class
Omerli	Elmali	Elmali	Alibeykoy	Elmali	Elmali
Elmali	Omerli	B.Cekmece	Omerli	Alibeykoy	Omerli
B.Cekmece	Alibeykoy	Omerli	B.Cekmece	B.Cekmece	Alibeykoy
Alibeykoy	B.Cekmece	Alibeykoy	Elmali	Omerli	Terkos
Terkos	Terkos	Terkos	Terkos	Terkos	B.Cekmece
Darlik	Darlik	Darlik	Darlik	Darlik	Darlik

Table 5 also reveals that the most critical group in Istanbul is trophic criteria. Within this framework, one of the reservoirs is in a state of transition from oligotrophic to mesotrophic, one is mesotrophic, three are in a state of transition from mesotrophic to eutrophic and the last one is already hypertrophic. This is additionally supported by the anthropogenic nutrient load subgroup within hydrographic and territorial criteria, which is closely related to the land use practice in the watershed. This compatible set of results points at the fact that eutrophication control in Istanbul is the priority issue and that this should actually start in the watershed, before nutrients reach the reservoirs. An investigation of the sources of the nutrient load has revealed that the main source is domestic use (Tanik *et al.* 1999), which originates mainly from settlements within the watersheds, indicating once more the importance of the control of settlements and provision of relevant infrastructure. These observations relate the vulnerability of reservoirs in terms of eutrophication to the main location of the origin of pollution, i.e. the watershed.

The second important group of pollutants in Istanbul was determined to be heavy metals, which are included in the Salinity, Special and Hygienically Relevant Criteria, providing justification for the need for the control of industries, the most significant polluting source adding to the heavy metal budget, in the watersheds.

Table 6 aims to rank the drinking water reservoirs of Istanbul together with their watersheds from the worst to the best in terms of each respective heading based on Tables 2–5. It can be observed from Table 6 that the most polluted resource with the worst overall and trophic class, Elmali, has the highest rank in terms of population density and urban land use and the second in terms of population. On the other hand, Darlik, with the best overall and trophic quality, has the lowest population, population density, urban land use and no industrial activity. Similar conclusions can be drawn for the other reservoirs, once again indicating the very significant impact of urban activities, settlements, population densities and industries on water quality (Beler Baykal 1997; Beler Baykal *et al.* 2000).

All of these observations point at the fact that urgent, sound decisions are needed to maintain the sustainability of those resources as drinking water supplies, which should also take the impact of the watersheds into account for controlling pollution at its source, before it enters the water body. Controlled housing practice with proper infrastructure to assure the sustainability of the drinking water reservoirs for their intended beneficial use, and limited industrial plants with relevant pollution control measures should be provided together with pertinent monitoring and control in order to maintain a better quality influent for the water treatment plants through source control. Wrong decisions and practice may bring the use of the reservoirs for water supply to an end, leading to the necessity of supplying water from distant resources, implying additional costs.

FUTURE PLANS FOR WATER SUPPLY

Considering the high population increase rate, it is obvious that the quantity of water needed in Istanbul will increase accordingly. Predicting the water demand to be about 1.3 billion $m^3\ yr^{-1}$ in 2010 and 1.6 billion m^3 in 2020, ISKI has launched projects for meeting this future demand (ISKI 2000). The first additional water supply reservoir, centrally located Sazlidere, is in the stage of being taken into service, at a capacity of 55 million $m^3\ yr^{-1}$. This will be followed by the Istranca system streams, located on the European side north-west of the city, which is planned to be completed by 2004 supplying about 150 million $m^3\ yr^{-1}$. Other future water resources are Yesilcay, a stage of which was taken into service in 2003, and Alacali, with capacities of 145 million and 20 million $m^3\ yr^{-1}$, respectively. Finally, Buyuk Melen at a distance of about 200 km from Istanbul, will be used to supply an additional 1.2 billion $m^3\ yr^{-1}$ of water after the completion of its three stages by 2020 (Gonenc *et al.* 1996*a*,*b*; ISKI 2000).

It can be observed that Istanbul has to resort to distant resources to supply the increasing water demand. This means extra expenditures especially for transport and pumping requirements from long distances. Obviously, if the quality of the present resources cannot be kept at acceptable levels, and sustainability of the water resources for their intended beneficial uses is not maintained, Istanbul has to bring water from those distant resources sooner than expected. In this case, the primary issue regarding water services will be one of feasibility and economy and a decision regarding which is more preferable: to keep current nearby sources clean through stringent control or to pump water from resources hundreds of kilometres away.

CONCLUSIONS

Urban elements in relation to land use in watersheds, such as settlements, population, population density and industry have a significant impact on water quality in drinking water reservoirs, which in turn has consequences regarding water services. The impact of territorial characteristics of the watershed is emphasized in this piece of work through the example of the Turkish megacity Istanbul. As a rapidly growing city with difficulties in keeping up with its master plan, Istanbul may represent a good example for other cities of the world today and in the future. The results summarized in this work have once more pointed to the significance of land use in watersheds and site selection for settlements and industry to maintain sustainability of acceptable water quality in the drinking water reservoirs, which has consequences for water services, especially in terms of the success of water treatment. The balance between watershed characteristics, land use and water quality is a primary issue regarding the quality and economics of water services.

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