A network model simulation proposal for river basin management plans (RBMPs) in Turkey

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Abstract: Turkey is a negotiating candidate country with the EU. Although Turkey has been developing its water resources policy taking into account of the present and future water needs of its growing population, developments at global level and the on-going EU accession process, it stands at a critical threshold value with regard to its per capita water demand and is expected to become a water-stressed country beyond 2030. Moreover, climate change impacts on water resources lead to irregularities in the flow regime, which constitutes an additional severe burden on water management Already heavy population in water scarce-regions has necessitated water transfer from adjacent basins. This management approach requires a comprehensive decision support system taking into account different situations. In this study, we aim to use a network simulation model within the Greater Istanbul Metropolitan Area that has been facing a heavy population increase caused by local immigration since the 1970's. We run the algorithm repeatedly for different random realizations of estimated inputs and we show that existing water resources are sufficient until 2040 with the projected demand, providing that existing resource conditions remain unchanged. Also the model results show that significant changes in resource replenishment, which may be generated by natural and anthropogenic adverse impacts, will draw back the horizon year of 2040.

Key words: Istanbul water supply system, water supply security, water transfer

1. INTRODUCTION

The city of Istanbul straddles two continents linked by three bridges and two undersea crossings at present. Its boundaries lie between $28^o\ 10'$ and $29^o\ 40'$ East longitudes and $40^o\ 50'$ and $41^o\ 30'$ North latitudes and extends to the Black Sea, both sides of the Golden Horn and Istanbul Strait (Bosphorus) on the Asian and European continents as shown in Figure 1a (UCTEA CEE, 2014).

The Greater Metropolitan Municipality of Istanbul, with its settlement area covering 5400 km^2 and a population of approximately 15 million, is a coastal mega city that has been attracting immigrants for many centuries. Natural growth and immigration resulted in exacerbated urbanization from the 1970s.

Yet the city does not have large rivers within its administrative boundaries that would ensure a reliable water supply. These socio-geographic and hydrologic constraints have given rise to significant challenging management issues since the 16th century. Heavy population increase caused by local immigration has resulted in a sharp rise in water demand since the 1970's. In response to this situation the State Hydraulic Works (DSI) and Istanbul Water and Sewerage Administration (ISKI) have launched comprehensive water resources development projects aiming at finding viable solutions in order to meet immediate and future demands. Water transfer from adjacent river basins and related management plans have been part of these remedial actions. During recent decades this solution has found widespread implementation in many water-scarce regions all over the world (Gohari et al., 2013). Similarly, water managers adopted this solution for the Istanbul water supply system.

This study presents a network model that is run in order to assess the water supply system for the near future, taking into account water resources within Istanbul, together with the Melen Project stipulated in the latest master plan as the most reliable resource external to Istanbul.

2. METHODOLOGY

Recent decades have seen widespread use of systems analysis to help manage water resources. (Harou et al., 2009).

In the present work, the basins of the creeks located in Istanbul and that of Istranca located in to the West are considered as a single basin and the total capacity of all the reservoirs is modelled by a single node, as shown in Figures 1a and 1b. In the same line, all water treatment systems are united in a single node. As it can be seen from Figure 2, the water supply system is supplemented directly or indirectly by the Yesilcay and Melen rivers located to the East of the city, some 100 km and 200 km respectively. For the purposes of global dynamics we consider these as a single external input to the Istanbul water supply system.
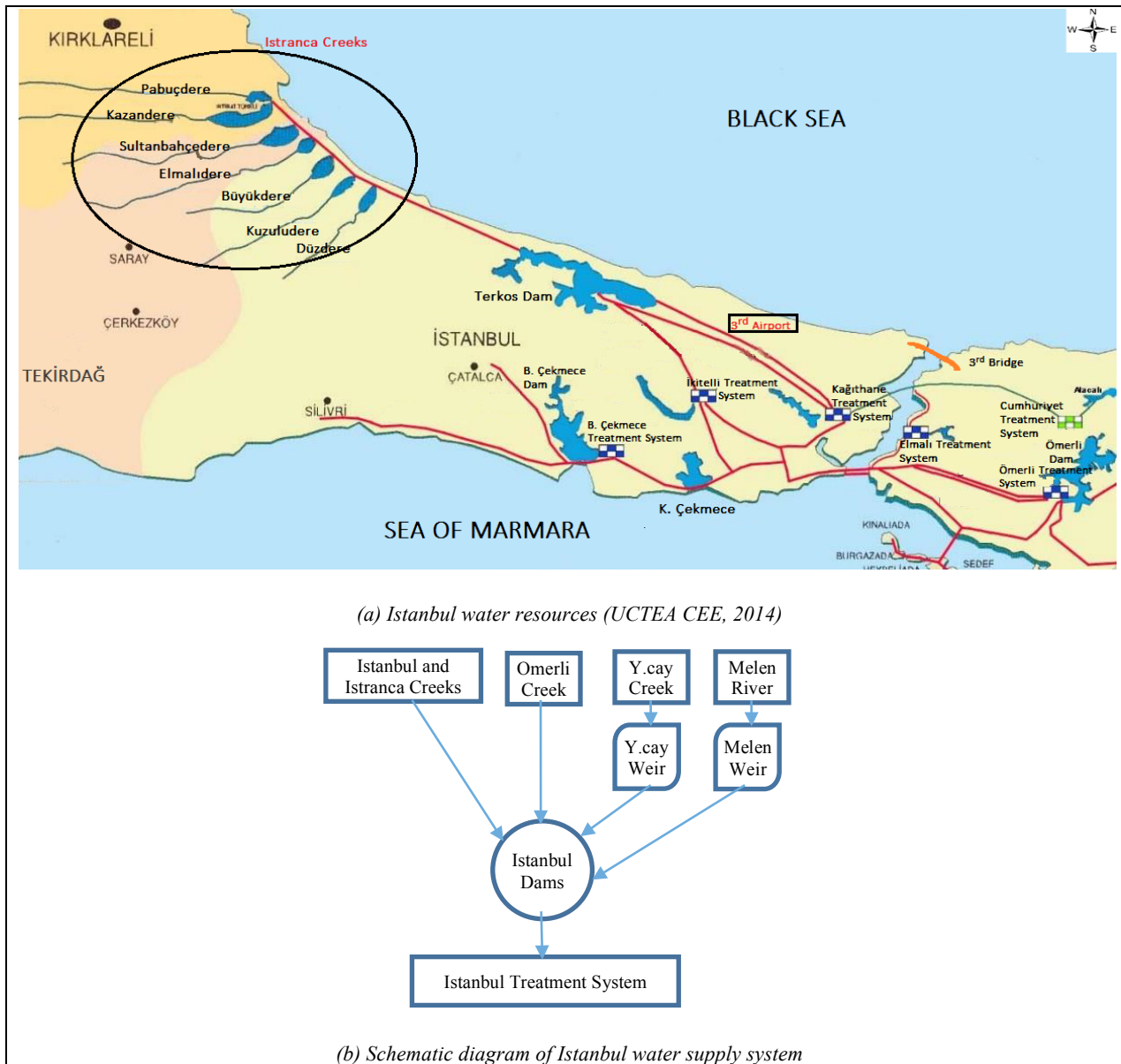

(a) Istanbul water resources (UCTEA CEE, 2014)

(b) Schematic diagram of Istanbul water supply system

Figure 1. Istanbul water resources and water supply system

The system composed of water catchment basins, reservoirs and water treatment plants is modelled as a network, as depicted in Figure 2. Additional updated data are gathered from ISKI and exchanges are made with ISKI officials (ISKI, 2015).

The major water supply at present is via the Yesilcay and Melen regulators. Omerli and Terkos dams that are located respectively in the Asian and European parts of the city are the main local

water supply. As shown in the figure, these major dams are interconnected to smaller ones that act as backup systems. Treated water is transferred to the various parts of the city. The network model for the detailed system will be investigated in an optimization framework in future works.
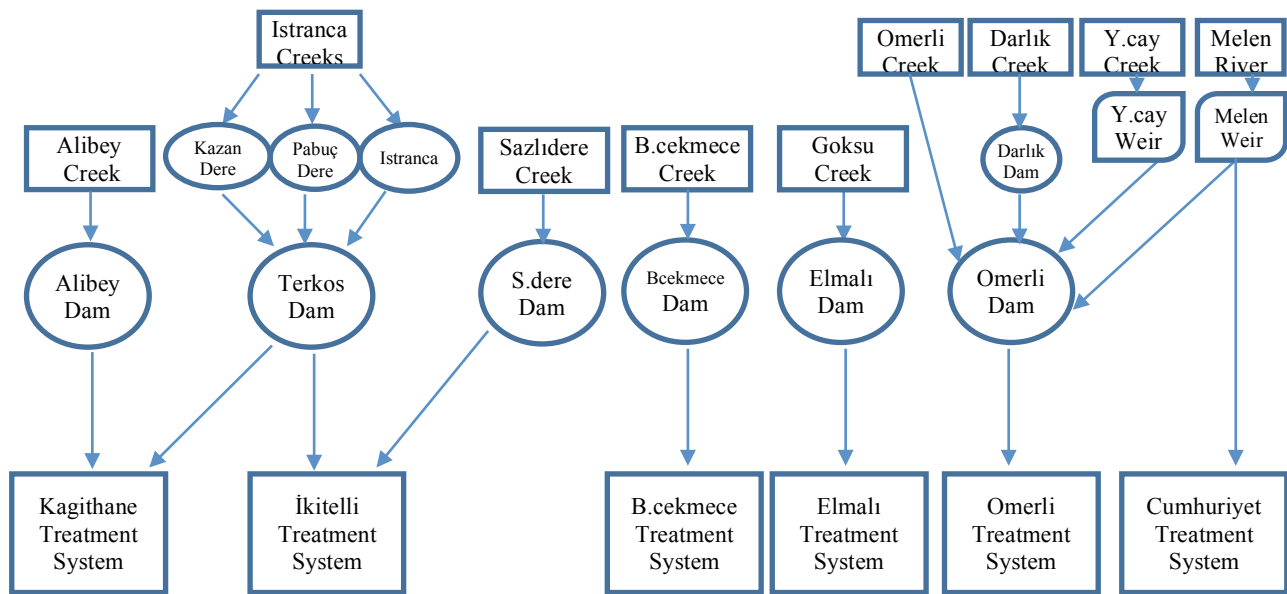

Figure 2. The detailed structure of the Istanbul water supply system

3. OVERVIEW OF THE CURRENT MASTER PLAN FOR ISTANBUL METROPOLITAN AREA

The current Master Plan entitled "Istanbul Water Supply, Sewerage and Drainage, Sewage Treatment and Disposal Master Plan Study" was launched in 1993 in order to replace the DAMOC Master Plan which became obsolete following the city's rapid expansion trend. Urbanisation spread towards rural areas, beyond planned urban boundaries, affecting the Omerli Water Catchment Basin in particular. This was due to meteoric migration into the Istanbul Metropolitan Area, driven by unforeseen socio-economic issues.

A severe drought in 1990, together with relatively dry periods with below average rainfall over the next few years resulted in extreme water shortages in Istanbul. Heavily rising demand due to population increase worsened the already difficult supply conditions, leading to rationing of water supplies throughout the city and in some areas water cuts lasting several days.

The water supply report of the master plan reviews existing infrastructure, together with the current status of planning for Istanbul and key factors that affect further infrastructure development. Water demand projections are then established for the Master Plan period, and an assessment made of the water resources available to satisfy those demands (IMC, 1999).

With the completion of ongoing resource development projects on the European side of Istanbul, there will be no further significant resources to exploit in order to satisfy rising water demands in that part of the city. Accordingly, future water resources development focuses mainly on the Asian side of the Bosphorus where DSI proposes to exploit the resources of the Melen River. This project, known as the Buyuk Melen System, will secure Istanbul's water demand throughout the Master Plan period until 2040. In 1991, a study was undertaken which established the feasibility of the Buyuk Melen System and made recommendations about the sizing and staging of the works. A primary task of the Master Plan was to verify the 1991 study and to update the proposals made in the light of new data available and the latest projections of population and water demand.

As part of this review, hydrological data has been re-evaluated and the safe yields of sources have been re-assessed. In addition, the conjunctive use of the various water resources serving Istanbul has been modelled to indicate the possible benefit that carefully managed source operation could bring in

terms of both increasing available supplies and in delaying the future development of new sources. A preliminary assessment has been made of groundwater sources. Water quality aspects of both ground and surface sources have also been considered.

Details of the existing water resources in Istanbul are presented in Table1.

Table 1. Details of Existing Water Resources (IMC, 1999; ISKI, 2017; DSI,2017)

Characteristics of Catchment Areas and Reservoirs	European Side				Asian Side		
	Terkos	Alibeyköy	B.Çekmece	Sazlıdere	Ömerli	Darlık	Elmalı
1. Drainage area (km^2)	619	160	622	165	621	207	76
2. Mean Annual Rainfall (mm)	750	837	700	627	880	880	-
3. Mean Annual Inflow (Mm^3/a)	163	54	219	49,2	236	108	32
4. Average runoff coefficient (%)	35	40	50	47	45	59	-
5. Reservoir							
5.1 Gross capacity	187	36	182	-	357	113	11.7
5.2 Dead storage (Mm^3)	42	1	20	-	122	6	0.2
5.3 Effective capacity (Mm^3)	162,241	34,143	148,943	88,730	235,371	107,500	9,600
5.4 Fully supply level (E.M)	4.5	30	6.3	48	62	52	67.5
5.5 Min. Operating level (E.M)	-1.00	11	0.8	-	46	21	37.5
5.6 Reservoir area at F.S.L (km^2)	39.0	3.0	36	-	22.4	7.0	1.2
6. Nominal annual draught (safe yield) Mm^3/a	142	36	70	-	220	97	14.7

In this work we focus our study on a quantitative approach and present several scenarios based on various resources regardless of policy decisions.

4. THE NETWORK MODEL

Let $U_i>0$ and $Y_i>0$ be respectively the net input to the reservoirs and the net water demand during year i. We use the realized and the potential water demand values for the years 1955-2040, as given in Table 2, to project Y_i beyond 2040 up to 2100 in terms of a sigmoidal model that can be applied in our research (Carrillo, 2003).

The output of the simulation depends crucially on the precision of the estimation of the water demand. In order to obtain reliable results for future planning the sigmoidal projection curve should be updated as needed, using current values.

The net input to the reservoirs, U_i, is modelled as a Gaussian random variable with mean and standard deviation computed from ISKI data. The adjustments for various drought scenarios and anticipated irregularities can be done by modifying the mean and the standard deviation, respectively.

Let W_i be the amount of water present in the reservoirs at the beginning of year i. Clearly, $0<W_i<W_0$ where W_0 is the total capacity of the reservoirs. We denote by X_i the water withdrawn from (positive sign) or added to (negative) the storage volume of the reservoirs during the year i. Let V_i be the amount of water input from external basin. V_i has to be less than the maximum yield of these sources, V_m. We will call U_i and V_i as local and external inputs respectively.

The algorithm given below stops when $W< - W_0$.

- If $U_i>Y_i+(W_0-W_i)$, then we use the local input only to meet the water demand, to fill the reservoirs and we discharge any surplus.
- If $U_i+Y_m>Y_i+(W_0-W_i)$, we use the local and external input to meet the water demand and to fill the reservoirs but there is no discharge.
- If $U_i+Y_m<Y_i+(W_0-W_i)$, we use the local and the maximal external input to partially meet the water demand and supplement it from the reservoirs.

Table 2. Potential water demand for Greater Istanbul (DSI, 1991)

Year	Population (1000)	Net Per Capita Demand (l/c/d)	Net Water Demand (million m³/year)	Unaccounted for Water (%)	Gross Water Demand (million m³/year)
1955	1 527	112	62	50	124
1960	1 874	120	82	50	164
1965	2 285	129	108	50	216
1970	3 020	138	152	48	292
1975	3 923	148	212	46	393
1980	4 787	159	278	44	496
1985	5 936	170	368	42	634
1990	7 475	182	497	40	828
1995	8 780	195	625	37	992
2000	10 110	212	782	34	1 185
2005	11 395	231	961	32	1 413
2010	12 584	244	1 121	30	1 601
2015	13 728	250	1 253	28	1 740
2020	14 683	255	1 367	26	1 847
2025	15 492	263	1 487	24	1 957
2030	16 120	270	1 589	22	2 037
2035	16 601	276	1 672	21	2 116
2040	16 963	284	1 758	20	2 198

We run the algorithm described above repeatedly for different random realizations of estimated input U_i., as presented in Figure 3. During the earlier phase at which the Yesilcay and Melen system was not operational, the fluctuations in the left end of the Figure 3 represent those in the local input U_i. During the intermediate period extending up to 2040, the Yesilcay and Melen systems and local input are sufficient to run the system without any net withdrawal from the storage capacity of the reservoirs, as anticipated in the Master Plan. But beyond that period, based on our sigmoidal projection, the system starts to fail, in the sense that during certain years, there is a net withdrawal from the storage capacity.
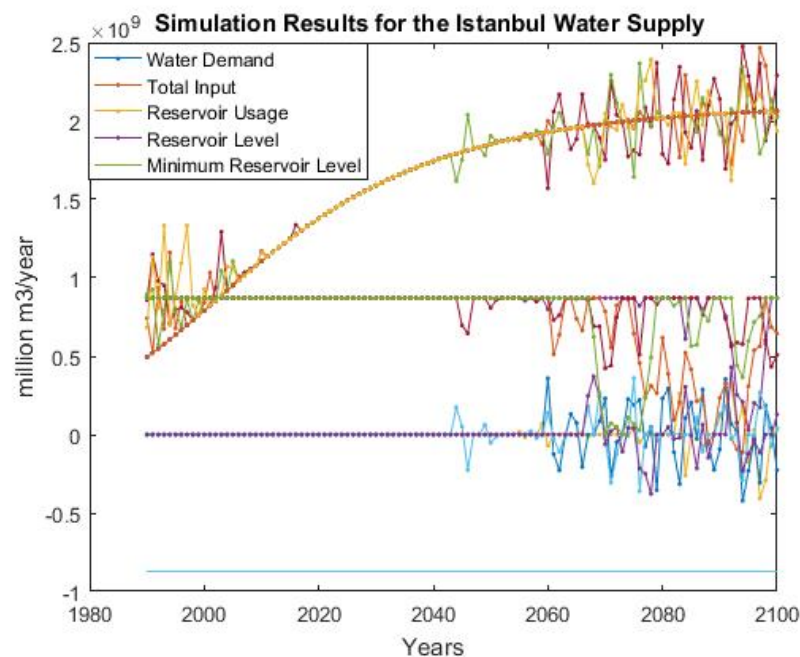

Figure 3. Simulation results for the Istanbul water supply system.

5. CONCLUDING REMARKS

The Master Plan assumes that prevailing conditions in the future will inevitably be different from

the ones projected throughout the given period. Therefore it has been emphasized that regular reviews should be made of the planning proposals in order to take account of demographic, economic, legislative and urban development changes in future years. Depending upon the extent and pace of change, reviews may be needed as frequently as every ten years on average. Applying this model gives us an assessment of the future situation and corresponding water demand and supply conditions.

Unpredictable issues like the severe hazard generated by the 1999 earthquake have been a reason for the development of the city to the north and northwest, where ground conditions are more suitable for housing. This new direction in urban expansion, followed by the construction of a third bridge across Istanbul Strait and the location of a new airport to the northwest may generate new urban expansion in this area.

The model results show that existing water resources will be sufficient until 2040, according to projected demand, providing that existing resource conditions remain unchanged. Also the model results show that significant changes in resource replenishment which may be generated by natural and anthropogenic adverse impacts will bring forward the horizon year of 2040. These impacts can be enumerated as follows:

- severe repeated droughts and extremes,
- anthropogenic impact on resource yield mainly caused by urbanisation to the detriment of forest areas,
- changes in run-off patterns within water catchment basins in Istanbul and in the external basins supplying water to Istanbul due to natural and anthropogenic hazards

In conclusion, first of all, water resource planning must continue to promote the diversification of Istanbul's water resources to help reduce the vulnerability of the city to future drought periods. Second, regardless of supply-sided water resource development, it is obvious that management policy decisions (e.g. minimising water losses, conserving resources by controlling demand, promoting reuse where practically feasible) have to be taken into account in the process. Third, in the case of water supply to Istanbul, all sustainable policy decisions must be applied by a common agreement and consensus among all stakeholders. Also compensation measures with regard to water quantity and quality must be discussed with the users of the adjacent basins (i.e. Melen River, in particular) in order to avoid other alarming water shortage situations, as occurred in 1990.

ACKNOWLEDGMENT

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