DEVELOPING ROADMAPS FOR THE SUSTAINABLE MANAGEMENT OF THE URBAN WATER CYCLE: THE CASE OF WW REUSE IN ATHENS

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EXTENDED ABSTRACT

In the context of water scarcity the interest in the reuse of treated wastewater as an alternative resource for non-potable uses has increased. Recent changes in the regulatory framework (JMD 145116/2011) and the introduction of guidelines and standards for reuse in Greece make a study of the implementation of wastewater reuse in Athens timely. The paper uses state-of-art metabolism modelling tools and approaches to develop and quantify a set of “roadmaps” towards wastewater reuse for the water company of Athens with the intention to support its sustainability agenda. The paper presents the candidate areas for wastewater reuse in Athens and describes the criteria for their designation, including assessment of suitable uses (such as industrial use, reforestation, crop irrigation, ground water recharge and urban and peri-urban uses) and estimation of their proximity to major Wastewater Treatment Plants (WWTPs). Different roadmaps are developed to assess the feasibility and quantify the effect of a progressive replacement of potable water with reclaimed water for the targeted uses and users. Each step of these roadmaps is simulated using the Urban Water Optioneering Tool (UWOT) which simulates and optimizes the entire urban water cycle, from source to tap. The paper concludes with a comparative assessment of the roadmaps based on the results of the simulations, taking into account the reduction of total water abstractions and the energy consumption for pumping and treatment of potable and reclaimed water. The results indicate that wastewater reuse can improve (a) the quantity and quality of surface and underground water; (b) the ecosystem services; (c) the efficiency of water use; and (d) the reliability of the existing water supply system of Athens.

KEYWORDS: treated wastewater; recycling; roadmaps; urban water management; simulation

1. INTRODUCTION

The interest in the reuse of treated wastewater as an alternative resource for non-potable uses has much increased in the last decades. Reclaimed water as such a resource is applied widely in many countries such as Australia, Israel and the State of California, where strategic plans for large scale implementation of wastewater reuse have been developed, recognizing this way the beneficial effect that reuse can have on sustainable water management (Rubin, 2001).

In Europe, there is great interest in the south and especially in countries such as Spain, Portugal, Italy, Greece and Cyprus, as well as in France and the United Kingdom where distribution of precipitation and runoff is uneven spatially and temporarily and the cost of making water available at the right place, at the right time with the required quality is too high (Angelakis et al, 1999). However, there are no centralized guidelines or a regulatory framework in EU. The only reference concerning wastewater reuse is made in the European Directive 91/271 (EU, 1991) according to which "wastewater reuse should be implemented whenever it is appropriate." As a result, each country has established its own criteria and guidelines for wastewater treatment. Therefore, it is necessary to develop common wastewater reuse standards and a centralized European policy, as well as methods that will allow the designation of roadmaps for the implementation of wastewater reuse.

The purpose of this study is to develop different roadmaps that describe the pathway towards large scale implementation of wastewater reuse in Athens, gradually increasing the amount of recycled water. The roadmaps will identify the alternative stages/steps, each corresponding to a different subproject.

2. CASE STUDY

2.1 Water supply system

The Athens external water supply system is an extensive and complex hydrosystem that is run by the Athens Water Supply and Sewerage Company (EYDAP). For the water supply service in the Company's area of service, EYDAP is supplied with raw water mainly from four surface water resources, Mornos, Evinos, Yliki and Marathon. Among the water supply resources used by EYDAP, are also included the underground water resources with the operation of 105 installed boreholes, utilizing groundwater aquifers. Some parts of the water supply network require energy for water pumping in contrast to other parts of the aqueducts where water is flowing by gravity. Raw water, after being collected at the four reservoirs, is transferred through the aqueducts to 4 Water Treatment Plants (WTP) where is treated, disinfected and then distributed to the citizens of Athens.

2.2 Sewage Network Operation

The sewage of the Athens Metropolitan Area is discharged at the Psyttalia island sea region after undergoing wastewater treatment at the Psyttalia Wastewater Treatment Plant. The total population served today is four million inhabitants. Apart from the domestic sewage, industrial waste is also collected (EYDAP, 2012). The WWTPs that will be considered in wastewater reuse implementation are the main WWTP of Athens which is Psyttalia (average annual wastewater flow of approximately 730 000 m^3/d) and secondarily the WWTP of Metamorfosis in order to take advantage of its elevation (with a capacity of 24 000 m^3/d of septic sewage and 20 000 m^3/d of municipal wastewater) and the WWTP of Megara and of Thriassio.

2.3 Areas and uses covered with reclaimed water

Reclaimed water will cover several urban and peri-urban uses except for domestic and potable use: crop irrigation, industrial use, reforestation, irrigation of parks, lawns and highway embankments, groundwater recharge, washing streets and other municipal needs. Based on the above uses and the proximity of each area to the four WWTPs, the regions of Athens where wastewater reuse is suggested to be implemented are (Adraktas et al., 2009):

- Athens coastline (Elliniko, Glyfada, Alimos, Voula, Faliro)
- The island of Salamina
- The area near Megara WWTP and Thriassio WWTP (Megara, Thriassio Pedio)
- Piraeus and the municipalities nearby (Perama, Keratsini, Drapetsona)
- The areas near Metamorfosis WWTP (Metamorfosi - Nea Philadelphia - Nea Ionia)
- Western neighbourhoods of Athens (Agia Varvara, Egaleo, Rentis, Peristeri, Elaiwnas)

3. ANALYSIS

3.1 Athens water demand

The water demand that can be covered with reclaimed water for several uses in the greater area of Athens is estimated for three seasonal periods (winter, intermediate, summer) (Table 3.1) in order to take into account the decrease of irrigation demand during winter, in contrast to industrial water demand which remains constant throughout the year. Moreover, the study area for the implementation of wastewater reuse has been separated into zones (Figure 3.1), which are essentially combinations of neighbouring municipalities according to the elevation of each area (Adraktas et al., 2009).

3.2 Baseline scenario

The entire urban water cycle of Athens was simulated in UWOT. The UWOT model (Makropoulos et al., 2008) is a complete urban metabolism model that provides a common modelling environment for the simulation of the whole urban water cycle which includes abstractions from the hydrosystem, transmission and distribution of water, water treatment, water consumption at the appliance level, sewerage network and treatment and finally disposal to the water bodies (Figure 3.1). For the simulation of the internal water system only one household type, with characteristics that correspond to the average household type for Athens, was used to represent the whole city (Rozos and Makropoulos, 2012).

Apart from the consumption of potable water, many industries nowadays consume large amounts of groundwater as well as seawater after being desalinated. In addition, many municipalities use boreholes either to irrigate crops or to cover other urban uses. Groundwater is also consumed for the irrigation of highways. Therefore, the energy required for water pumping in boreholes as well as the energy required for the desalination were estimated.

3.3 Roadmaps

The first roadmap is a conservative and realistic approach to the implementation of wastewater reuse in Athens. It is estimated that it will last at least 20 years until it is completed, taking into account similar projects in other countries. Considering the current situation in which there is no wastewater reuse, and the difficulty in the social acceptance of replacing conventional resources with reclaimed water, the target is to cover about 30% of the total demand of the study area. Apart from centralized wastewater reuse, greywater recycling at household level is also implemented in all four roadmaps. More specifically, the first step of roadmap 1 includes the reuse of 55000 m^3/d reclaimed water from Psyttalia WWTP, the second one 25000 m^3/d from Metamorfosis WWTP, the third one 18000 m^3/d from Megara and Thriassio WWTPs, the fourth one 107000 m^3/d from Psyttalia and 36000 m^3/d from Megara and Thriassio and finally the fifth step includes the implementation of greywater recycling in approximately 25% of total households.

Table 3.1 Water demand by use and by zone (m^3).

	Annual demand	Maximum daily demand		
		Winter	Intermediary	Summer
Crop Irrigation	21766500	0	65300	188643
Industries	34957944	97105	97105	97105
Reforestation	15613004	0	44758	112166
Urban green spaces	9812103	0	229	68685
Highways	259093	0	6	1791
Total	82408644	97105	207398	468390

	Daily water demand	
Zones	Winter	Summer
A	0	25885
B	0	86282
C	0	56892
D	95609	118683
E	507	12028
F	0	36712
G	607	9375
H	383	12756
I	0	6995

Roadmap 2 is a less conservative plan than Roadmap 1 since the total amount of wastewater reused is greater throughout all five steps of the second roadmap. The capacity of Psyttalia is much increased and its maximum wastewater discharge is 135000m^3/d. In Roadmap 3, greywater recycling is implemented more gradually, although the centralized wastewater supply (from WWTPs) is the same with roadmap 1. Finally, roadmap 4 includes only the Psyttalia, Thriassio and Megara WWTPs. This roadmap will be implemented in case Metamorphosis WWTP treats industrial wastewater from Asopos River, which makes the plant inappropriate for providing treated wastewater for reuse.

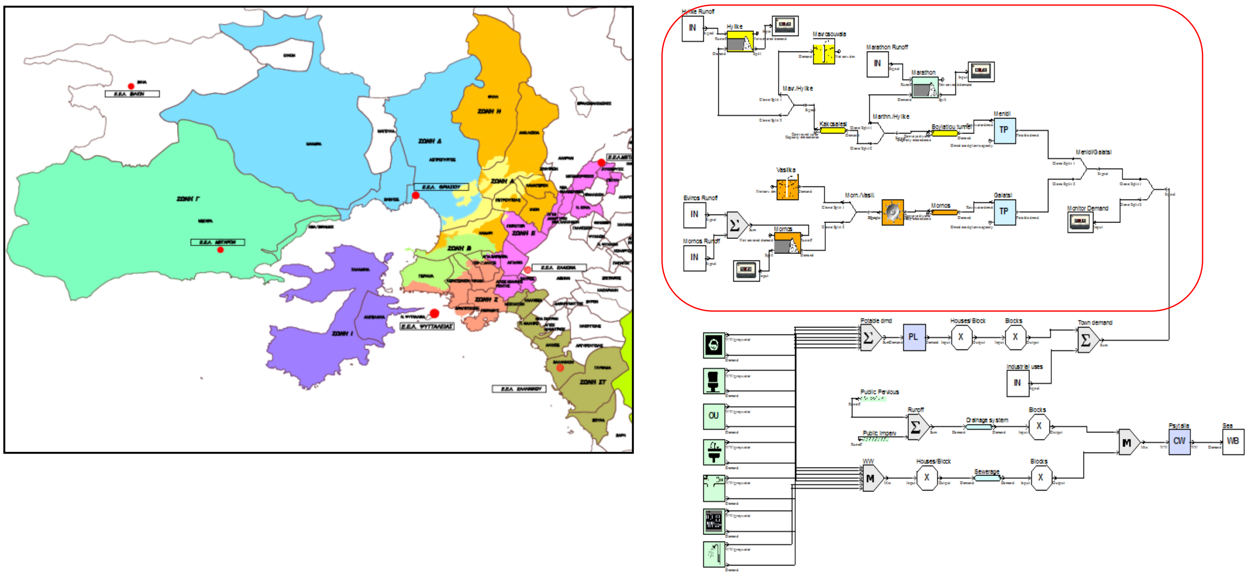


Figure 3.1. Left panel: Study area separated into zones (Source: Adraktas et al., 2009). Right panel: Simulation of the external water system (within the frame) and the internal water system in UWOT.

4. Results

4.1 Potable water demand fluctuation

Due to wastewater reuse, the demand of potable water decreases from 32.03 hm³ per month, which is the current consumption, to 31.35 hm³ (Figure 4.1). The decrease of water demand is also obvious in the monthly timeseries returned by UWOT, which are the results of the simulation during the period 01.01.1996 - 01.09.2010 (Figure 4.1). The reason of the decrease is the replacement of potable water with reclaimed water mainly in industries. This demand can be covered with reclaimed water from the first step of each roadmap. Actually, there might be a further decrease in the potable water consumption since it was taken into account that urban uses are covered today exclusively with groundwater. In all roadmaps, there is also a decrease in water demand at the end of step 5 due to the implementation of greywater recycling in households, whereas in roadmap 3, there is a further reduction in step 3, where greywater recycling is inserted into the urban cycle and is implemented progressively.

4.2 Total abstractions

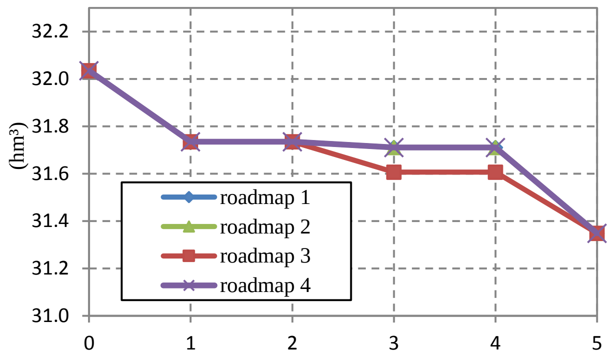
The reduction of total abstractions (including potable water of EYDAP, groundwater and seawater) is significantly greater than the reduction of the demand of potable water of EYDAP (Figure 4.2-left panel) throughout the steps of roadmap 1. Figure 4.2 (right panel) shows the fluctuation of potable water demand if current needs (crop irrigation and industries) or future needs (urban regeneration and reforestation) are covered either with reclaimed water or with EYDAP potable water. Due to wastewater reuse, a significant amount of water (the area between the two lines) is allocated towards ecosystems services, which would otherwise (no wastewater reuse) be abstracted from water resources.

4.3 Energy consumption for pumping potable and reclaimed water

Due to the reduction of water demand, there is also a decrease in the energy consumption for pumping water from water resources (Yliki Lake and boreholes) in the external water system of Athens (Figure 4.3). However, the energy required for pumping reclaimed water rises significantly (Figure 4.3) due to the gradually increasing amount of recycled water. The upward trend in roadmap 2 is considerably greater than the equivalent in the other two roadmaps, since the amount of reclaimed water is higher throughout all five steps of the second roadmap. The estimated balance of the total energy cost between the baseline scenario and roadmap 1 is positive (Figure 4.4). The energy consumption is given in CO_2 emissions (1 kg CO_2/kWh) according to the Public Power Corporation S.A. (DEI, 2009) and includes the energy required for pumping potable water (EYDAP) and groundwater and for the desalination of seawater in the baseline senario. By implementing wastewater recycling, energy is consumed exclusively by EYDAP for pumping both potable and reclaimed water.

4.4 Energy required for the treatment of potable and reclaimed water

The energy required for the treatment of potable water of EYDAP decreases as expected since the demand of potable water declines as well due to its replacement (to an extent) with reclaimed water (Figure 4.4). The total energy for the treated wastewater is consumed in secondary and tertiary treatment of effluents in WWTPs (centralized) and in greywater recycling appliances in households (decentralized). The energy consumption for secondary treatment (0.5 kWh/m³ (Fane)), is almost steady (Figure 4.5).



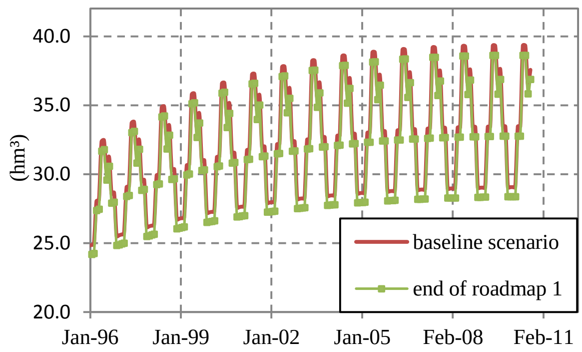


Figure 4.1. Potable water demand per month (EYDAP) throughout the five steps of roadmaps (left panel) and timeseries of potable water demand per month (right panel).

The energy required for tertiary treatment with membrane-technology system (0.9 kWh/m³ (Fane)), rises due to the gradually increasing amount of recycled water. The greatest growth corresponds to roadmap 2 and the lowest to roadmap 4 (conservative roadmap, without any wastewater recycling from Metamorfosis WWTP). The energy in roadmap 3 is slightly higher compared to roadmap 1 due to greywater recycling, starting at step 3 of roadmap 3. This energy, although it is a small proportion of the total energy consumption (Figure 4.5-right panel), is consumed in households (decentralized) and not in the Wastewater Treatment Plants (centralized).

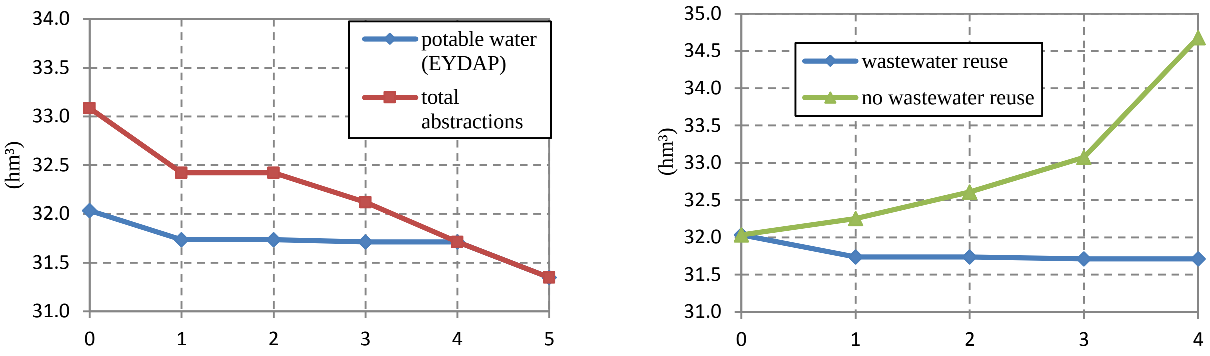


Figure 4.2. Monthly fluctuation of potable water demand and of total abstractions throughout the steps of roadmap1.

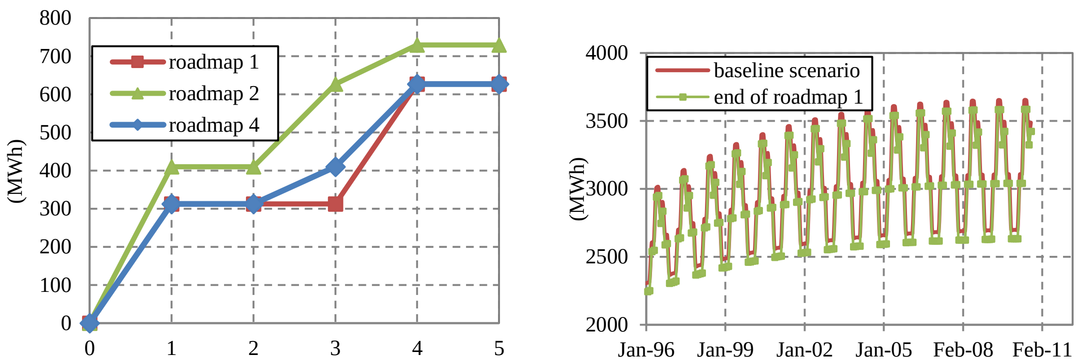


Figure 4.3. Monthly timeseries of energy consumed for pumping water from water resources (left panel) and energy required for pumping treated wastewater (right panel).

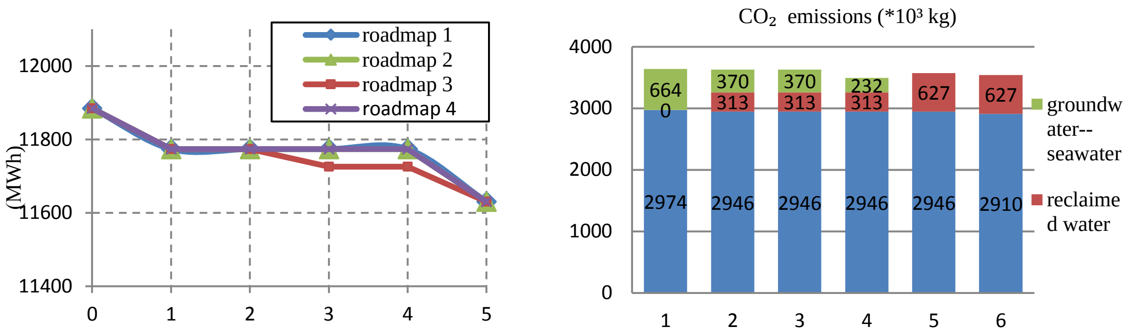


Figure 4.4. Energy required for pumping in baseline scenario (1) and throughout the steps of roadmap 1 (2-6) (left panel) and for potable water treatment (right panel).

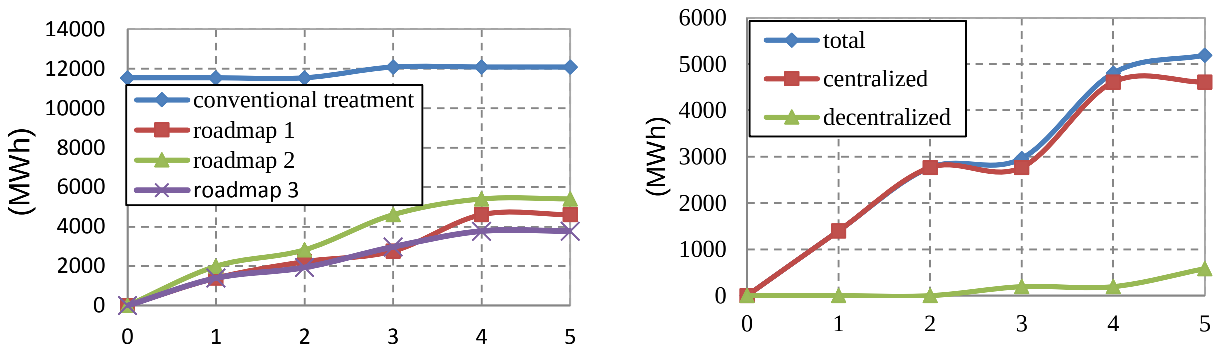


Figure 4.5. Energy required per month for the conventional and advanced treatment of wastewater (left panel) and energy required for the advanced treatment of wastewater throughout the five steps of roadmap 3 (right panel).

5. Conclusions

- As far as the environmental benefits are concerned, the decrease of Athens water demand, although quite slight, is very important taking into account the great distance of the main water resources of the external water system from the city of Athens. By implementing wastewater recycling, the total water abstractions are significantly reduced, whether it concerns fresh water pumped from water resources or seawater. Consequently, the degradation of aquifers will eventually slow due to less groundwater pumping and groundwater recharge with reclaimed water as well. Furthermore, as reclaimed water will cover not only current needs but also future needs, such as reforestation and urban regeneration, apart from the reduction of future water abstractions, a great amount of treated water will be allocated towards ecosystem services. Therefore, humans will benefit from the improvement of existing ecosystem services and from the development of new ones. Obviously, the decrease in total water abstraction, the efficiency of water use through water recycling and the benefits from ecosystem services and functions comply with the objectives of the Blueprint (EU, 2012) which ensures a sustainable balance between water demand and supply as well as sufficient quantity of good quality water available for people’s needs and for the environment.
- Taking energy consumption into consideration, the total energy cost for pumping potable water, groundwater and for the desalination of seawater today is higher than the energy required for pumping potable and reclaimed water in roadmap 1. The energy required for pumping water in the external water system decreases similarly to water demand reduction, regardless of which roadmap is implemented. If the energy required for the tertiary treatment is also taken into account, then the energy balance is negative in all roadmaps. However, the significant reduction of environmental cost which would undoubtedly outweigh the negative balance of energy consumption has not been estimated. Moreover, it must be pointed out that the estimated energy required is currently consumed by EYDAP and some industries and municipalities that desalinate seawater and pump groundwater, while in future it will be consumed only by EYDAP. Moreover, a small part of this energy cost will be attributed to individual consumers who will use greywater recycling appliances at the final step of the roadmaps. However, the distribution of this cost depends, to a great extent, on the response of Athens water system stakeholders to wastewater reuse.
- Given the fact that the hydrosystem of Athens operates today within the limits of its reliability, as it is difficult to ensure a reliable operation of 99% under the current conditions (Makropoulos et al., 2010), it is evident that even a small reduction in water demand will improve the system operation and decrease the reliability risk. In addition,

recycled water can have the advantage of being a constant and reliable water source, which does not depend on environmental factors such as uneven rainfall and drought.

6. Acknowledgements

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