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CREATING INCENTIVES FOR MORE EFFECTIVE WASTEWATER REUSE IN THE MIDDLE EAST AND NORTH AFRICA

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Abstract

The reuse of treated wastewater is often discussed as an attractive option for addressing water scarcity, yet systematic water recycling remains rare in many arid and semi-arid countries, for example in the Middle East and North Africa (MENA). This paper addresses how the economics of reuse may contribute to this paradox, emphasizing the role played by unresolved incentive problems with management of the externalities associated with wastewater discharges. A simple conceptual model with two users—one high-value (e.g. municipal/industrial) and the other low-value (e.g. agricultural)—is developed, and related to current conditions in MENA countries. This model is used to explore first the reasons for which widespread wastewater reuse remains a significant challenge, and second a series of policy-relevant cases for expansion of reuse, including their implications for social welfare. MENA countries are then classified into a typology according to how they relate to the cases. The paper closes with a series of recommendations for improving water and wastewater management, and on the appropriateness of reuse, in different types of MENA countries.

ملخص

يعتبر موضوع إعادة استخدام مياه الصرف الصحي المعالجة مدخلا جذابا لموضوع معالجة ندرة المياه، ولكن منهجية إعادة تدوير المياه لا تزال نادرة في العديد من البلدان القاحلة وشبه القاحلة، على سبيل المثال في منطقة الشرق الأوسط وشمال أفريقيا (MENA). وتتناول هذه الورقة كيف يمكن للاقتصاد أن يسهم في اصلاح هذا التناقض، والتأكيد على الدور الذي لعبته مشاكل الحوافز العالقة مع إدارة العوامل الخارجية المرتبطة بتصريف مياه الصرف الصحي. تم تطوير نموذج نظري بسيط يتكون من اثنين من المستخدمين واحد ذات القيمة العالية (مثل المحلية / الصناعية) ، والأخرى ذات القيمة المنخفضة (مثل الزراعة) ، ويتصل بالظروف الراهنة في بلدان الشرق الأوسط وشمال أفريقيا. ويستخدم هذا النموذج أولا لاستكشاف الأسباب التي مازالت تجعل من إعادة استخدام المياه المستعملة على نطاق واسع تحديا كبيرا ، وثانيا لطرح سلسلة من القضايا ذات الصلة بالسياسات من أجل توسيع نطاق استخدامها، بما في ذلك آثارها على الرفاه الاجتماعي. ثم يتم تصنيف بلدان المنطقة وفقا لمدى صلتها بالحالات.تختتم ورقة بسلسلة من التوصيات لتحسين إدارة المياه ومياه الصرف الصحي ، وعلى مدى ملاءمة إعادة الاستخدام ، في مختلف أنواع بلدان الشرق الأوسط وشمال أفريقيا.

1. Introduction

The scarcity of freshwater in most countries of the Middle East and North Africa (MENA) region is an increasingly acute problem, particularly as their populations continue to grow, placing higher demand on water resources. Today, 14 of 20 MENA nations are classified as being in water deficit, which is defined as less than 500 m3 of renewable water supply per capita per year (FAO 2010). Projections of population growth suggest that four of the remaining MENA countries are likely to join that group over the next half century (United Nations 2010). There is also growing consensus among scientists that climate change will reduce precipitation and increase temperatures in MENA countries; both of these trends seem likely to increase stress on regional water resources (IPCC 2007).

Faced with the increasing scarcity resulting from these evolving conditions, MENA governments, decision-makers and planners have become interested in tapping non-conventional water resources, such as recycled wastewater, and desalinated brackish or salt water, to meet demands for water. Of these options, wastewater reclamation is often touted for its "inherent" benefits, which include: the ability to augment water supplies through replenishment of groundwater or surface water resources, the preservation of better quality water resources for particularly high-value uses such as potable water, the environmental protection obtained through improved wastewater management and reduced abstractions from surface waters, and the postponement of more costly water supply approaches such as storage schemes and desalination (Scott et al. 2004; Asano et al. 2007).

Yet despite such perceived advantages, few countries have succeeded in developing successful and safe wastewater reuse programs, even if many have demonstrated considerable innovation in the water sector in general (Bucknall et al. 2007). This paper builds on previous work to argue that much of the relative failure to make greater use of reclaimed wastewater in MENA in particular can be linked to incentive problems related to managing the externalities associated with wastewater discharges (Kfouri et al. 2009). Because these externalities have rarely been accounted for and dealt with, it is generally quite difficult to encourage investment in approved and safe reuse. Agents who discharge wastewater rarely if ever bear the high cost of its conveyance and treatment to reuse standards, and irrigators, who themselves do not pay the full cost of water supply, have little economic reason to opt for recycled water unless they have no choice.

A simple conceptual model that includes two types of agents is developed: the first, a high-value water user (perhaps a municipal / industrial user), and the second, a low-value water user (for example an irrigator). This model is used to explore first the conditions that make widespread wastewater reuse a challenge, and second a series of policy-relevant cases for expansion of reuse. In the first two cases, water users are free to choose among alternative supplies (one taken from the natural environment and the second being recycled wastewater), which are differentiated by price and perceived quality, and constrained in total quantity.[1] In the third and fourth cases, users cannot choose between alternatives; the water is either mixed with conventional supplies to create a single homogeneous product that is delivered to users, or it is allocated separately to users by a water manager who can control their access to alternative supplies. The economics of several of these cases are discussed with reference to data on pricing and the wastewater sector in MENA.

The paper is organized as follows. The next section presents some details and simple calculations that establish the context of wastewater reuse in the MENA region. Section 3

1 Note that the emphasis on "perceived quality" is important because it is possible for treated recycled water to be at least as good, if not better than conventional sources, at least with regards to official water quality standards, if advanced treatment processes such as reverse osmosis are used. Even so, there are frequent and easily understood objections to using such recycled water for drinking purposes.

presents the key insights obtained from a simple conceptual model (with additional details and graphs explaining the cases available in the appendix), relates it to examples of reuse in MENA, and discusses the role that pricing plays in affecting the economics of reuse. Section 4 describes the relevance of this model to actual practices in MENA countries, examining real data on prices (when available) and delivery modes, and making connections to the reuse context described in section 2. Section 5 synthesizes observations on the general potential of reuse, and develops a set of policy recommendations for furthering it. Section 6 concludes.

2. Current Wastewater Treatment and Reuse in the MENA Region

Experience with wastewater reuse—here defined as the addition of treated wastewater back into a country's water balance where it can be put to productive uses in irrigation, industry, or for environmental purposes—in the MENA region is widespread.[2] This recycling can be direct, meaning that storage and conveyance infrastructures transport effluents from treatment works straight to the site of application, or indirect, when treated wastewater is discharged into surface waters or aquifers. Kfouri et al. (2009) review the published and gray literatures and find that nearly all countries in MENA are involved in some reuse, albeit with varying levels of success. Even today, most documented initiatives of treated wastewater reuse remain pilot initiatives; this suggests that the challenge of scaling up this technology has not fully been met.

One important reason for this appears to be the presence of two important hurdles that impede the potential for planned reuse applications: the low rates of a) collection and b) treatment of wastewater in the region (see Table 1). The Wastewater Reuse Index (WRI; rate of actual over potential reuse) depends on both of these factors as well as the fraction of treated wastewater that is actually recycled. Thus, insufficiency in any one of these three dimensions drives down reuse rates. With regards to the first two factors (collection and treatment of wastewater), the hurdles are partly financial: investments in piped sewerage and wastewater treatment are very expensive, adding on average about $1.1 per cubic meter to the cost of water delivered to households (Whittington et al. 2009). This amount represents slightly more than half of the total cost of network water and sanitation services, which cost about $2 per cubic meter of water on average. The hurdles are also partly economic: unlike the case of piped water, for which incentives are aligned because households must usually pay for investments in order to obtain services, most of the benefits of sewerage are diffuse health and aesthetic gains that only accrue to the community as a whole. In many MENA countries, it is not uncommon to find high percentages of the population in dense urban areas still using septic tanks (data from the Joint Monitoring Program (JMP) of the World Health Organization and UNICEF (2010)).

Indeed, evidence from around the developing world shows that sewerage lags well behind coverage with other municipal services, such as piped water, electricity, and telephones (Komives et al. 2003). Data from the JMP (2010) shows that the average level of piped water coverage across MENA countries is about 80% (ranging from 28% in Yemen to 100% in Israel and Kuwait), while sewerage is only about 60% (ranging from 12% in Yemen to nearly 99.6% in Kuwait, see Table 1 column C).[3]

2Unplanned wastewater reuse is also common in MENA and the developing world, despite health concerns. This is when untreated sewage is applied onto agricultural lands or discharged into surface waters or the environment from which it is again withdrawn for consumptive uses. The economic implications of unplanned reuse are very different from those of treated reuse, as will be discussed in section 3 of this paper.

3All data presented in this section should be treated with caution, as they appear to be somewhat inconsistent across years and countries. But while specific estimates for particular countries may be inaccurate, it seems safe to say that the situation of incomplete sewerage, less treatment than sewerage, and even further reduced reuse rates generally applies across the region. Some of the numbers are not too far from estimations based on more detailed wastewater accounting surveys conducted in specific countries; see for example Abu-Madi (2004).

The benefits of wastewater treatment relative to sewerage, which at least removes wastewater from the immediate household and community environment, are even further removed from water consumers; these mainly accrue to people living in low-lying urban areas or downstream of large municipalities. In MENA, much of the wastewater collected via sewerage systems is untreated or receives minimal treatment (Table 1 column D) prior to discharge into the sea or disposal in other surface water bodies and on land (from where it may go into unplanned reuse). In the absence of strong government enforcement or regulation of wastewater discharges, the externalities associated with wastewater conveyance investments and treatment therefore make the sanitation sector an obvious candidate for free riding behavior. Upstream users have little incentive to treat wastewater discharges which then pollute downstream water supplies. This situation compromises the ability of downstream locations to use recycled wastewater safely and effectively, since someone must pay for the conveyance infrastructures and construction and maintenance of treatment plants.

Rich countries like Kuwait and Bahrain, which have managed to create effective systems for collecting and treating nearly all of their wastewater, can more easily benefit from reuse, because the financing of reuse does not entail paying for these components of wastewater management. In contrast, countries like Egypt, Iraq and Yemen, with relatively low rates of sewerage, or Libya, Lebanon and Morocco, which treat very little of their wastewater, have a steeper road to climb before planned reuse becomes widespread.[4] Similarly, additional complications occur where operation and maintenance of conveyance and treatment infrastructures is neglected, as these may stop producing recycled water that meets the standard for reuse. All of these issues confront the countries and locations where unplanned reuse is most prevalent. Some analysts argue that economic calculations for reuse projects require that "…only the marginal cost of wastewater recycling (additional treatment, storage, and distribution) be considered, excluding the cost of wastewater collection and treatment" (Lazarova et al. 2001). However, this is only true if these services are in place and functioning in the absence of the recycling investment (Kfouri et al. 2009).

In order to better understand these potential financial barriers, let us briefly consider the costs of conveyance and treatment of wastewater and distribution for reuse (Table 2). Sewerage costs vary substantially as a function of urban density, topography, and the nature of the housing stock, but Whittington et al. (2009) estimate that conveyance infrastructure costs on average US$0.8 per cubic meter of water delivered. These costs can be substantially reduced, to US$0.3/m^3, by using condominial sewer technologies, but the use of such low-cost technologies severely limits the potential for wastewater reuse, which must then occur very near to collection sites (perhaps for urban landscaping or some types of gardening). The costs of wastewater treatment also depend on the technology that is used, the quality of water required before discharge, and the availability of land. Lee et al. (2001) estimate average treatment costs to be US$0.53/m^3 (range 0.46–0.74). These are somewhat higher than the $0.3/m^3 total estimates presented by Whittington et al. (2009) and others (see Table 2). In any case, it is easy to see that financing wastewater collection and treatment through a project for wastewater reuse will be extremely challenging unless the marginal product of reused water is very high. In some instances, the wastewater conveyance and treatment components may even exceed the $0.5-1.5/m^3 costs of alternative options such as desalination. The other important cost of reuse, which will vary across supply alternatives depending on the relative distances to the reuse sites, is distribution of treated water back to demand locations; this varies from US$0.05-0.36/m^3, and represents a lower bound on the cost of reuse in places where sewers and treatment are already in place.

4 Morocco has however been moving quickly to expand wastewater treatment capacity (see recent coverage of improvements at: http://www.globalwaterintel.com).

The fact that the WRI is low in so many MENA countries with water scarcity problems (for example in Bahrain, Libya, Egypt, Morocco and Tunisia) suggests that there are factors besides the lack of wastewater conveyance and treatment that restrain reuse in the region (Table 1 column F). It could be related to the demand for recycled water, whether because a) the marginal product of reused water is lower than the cost of delivering it, b) the prevailing prices for alternative sources are highly distorted (due to subsidies for irrigators), or c) users are sensitive to real or perceived differences in quality between conventional and reuse supplies. Financial barriers may also play a part, given that the infrastructures for distribution of recycled water require yet another investment in capital intensive civil works like irrigation canals or piped water systems. The next section uses simple graphical analyses to illustrate some of the realities facing the reuse sector in MENA. A few countries, like Israel and Jordan, reuse almost all of their treated wastewater; these cases will be discussed more fully in section 4.

3. A Simple Conceptual Model and Typology of Wastewater Reuse

This section presents the main results and insights obtained from a simple static model of conventional and reused water markets. The model includes two types of agents: the first, a high-value water user who is sensitive to real or perceived water quality and requires tertiary treatment prior to reuse, and the second, a less quality-sensitive, low-value user who requires a lower level of treatment. Though the description focuses on two user types, the general conclusions obtained could be applied and extended to a larger and more diversified set of actors. In the MENA context, this differentiation in users applies across sectors, for example irrigation (low-value) versus municipal and industrial (high-value), as well as within sectors, for example, for low-value grain producers versus high-value growers of fruits and vegetables, or for different classes of municipal or industrial customers. A complete graphical presentation of the cases in the typology described in this section is provided in the Appendix.

3.1 Understanding the motivation for reuse

For simplicity, assume that users face a horizontal price curve for raw (untreated) water from the conventional water supply up to the capacity limit $\bar{Q}$, after which no more water is available. The high and low-value user types have demand for water from the conventional water supply D_H and D_L, respectively, such that total demand $D_T = D_L + D_H$. If the price of raw water from conventional sources is $p_1{}^*$, the total demand is $q_1{}^*$, and there is no shortage (Figure 1). However, if the price of the water supplied is $p_2{}^*$, total quantity demanded $q_2{}^*$ is greater than $\bar{Q}$, and there is water shortage $\varepsilon_2 = q_2{}^* - \bar{Q}$.[5] This latter situation is the typical one encountered in the MENA region.

There are several possible ways of addressing this shortfall. The first is to raise the price of water until the total quantity demanded is reduced below $\bar{Q}$. In most countries in the MENA region, indeed throughout the world, water is priced well below the full cost of supply, as will be discussed in section 4. Raising the price to achieve cost recovery would go a long way towards reducing the quantity of water demanded to levels below the volume of available renewable resources. If water demand still exceeds water availability at cost recovery prices, water rates could be raised further to internalize the scarcity value of the resource. No additional water would need to be supplied; users willing to pay less than this equilibrium price, at the intersection of $\bar{Q}$ and D_T, would no longer buy water.

5 Note that there may be additional costs associated with providing finished water to such high-value users, which are generally reflected in differentiated and higher prices for that sector. For simplicity, in this paper we only include the price of raw water, before such finishing treatment.

Raising water rates is often politically unpalatable, however. The agriculture sector and the poor would bear the brunt of higher water prices, and governments that tout the benefits of improved food security and protection for the poor have usually been unwilling to risk the political backlash that high water rates might entail (Perry 2001). Thus, a second solution is to use non-price rationing devices, i.e. reducing the reliability of water delivery to selected users or to the population as a whole, to allocate water or simply to drive down demand. Unfortunately, the costs of a policy of reduced reliability are often high, and its success in reducing demand may be less than anticipated. Individual water users faced with low supply reliability routinely invest in storage tanks or increase pumping of groundwater supplies in order to maintain water consumption during periods of interrupted supply (Rogers et al. 2002). Low reliability may also create health risks for water consumers, due to problems associated with pressure fluctuations in the distribution system, or of storing water for extended periods at the point of use. Other typical coping behaviors include wasteful irrigation practices (flooding one's fields whenever possible), or delaying investments in conservation technologies like drip irrigation that rely on dependable services.

A third and often more politically attractive solution is to identify and develop new, alternative supplies of water. In most MENA countries, available surface and groundwater sources have long been tapped, and the remaining possibilities for expanding water supply are a) reuse or recycling of wastewater, and b) desalination. Desalination is costly, ranging from \$0.5-1.5 per m^3 without accounting for distribution costs if water must be moved inland, energy-intensive and polluting (due to issues with brine disposal), and likely only feasible for the very highest-value users unless large subsidies are provided (United Nations 2001, Kfouri et al. 2009). The high costs of desalination, combined with the promise of improved wastewater management and treatment, explains much of the attraction of wastewater reuse.

For recycled wastewater to be considered viable, however, two important conditions must be met. For one, the cost to a user of buying reused water must not exceed her willingness to pay (WTP) for that water, otherwise she will not buy it. Second, the users choosing to buy recycled water must also be the ones who would increase their consumption at the prevailing price for conventional water supplies, but who cannot do so because of shortages and rationing. Otherwise, no users experiencing the shortfall at that price will purchase recycled water, and the shortfall will remain. In other words, those suffering shortfalls must be content to use at least some recycled wastewater in place of the water they lack from the conventional source.

In what follows, four illustrative cases that generally pertain to the wastewater reuse landscape in the MENA region are described and related to these realities:

1. The relative price for recycled water is too high → No viable reuse;
2. The conditional demand for recycled water is too low → Limited reuse may be possible;
3. Recycled water is mixed with conventional supplies → Reuse is likely; and
4. Recycled water is supplied to specific user types via separate systems→ Extensive reuse may be possible.

Cases 1 and 2, in which user source choice is preserved, are most common, but these also make the expansion of reuse difficult. Cases 3 and 4 correspond to reuse policies that often lead to greater water recycling. A complete graphical description of these cases can be found in the appendix of this paper.

3.2 Case 1: Price for recycled water is too high → No viable reuse

Case 1 is trivial but common, and applies where the cost of wastewater reuse confronting potential consumers exceeds demand. This is the general situation that precludes most private investment in planned wastewater.[6] As illustrated by the numbers in table 2, the full cost of reuse may be high for many reasons, including the fact that effective wastewater management, collection and treatment, is expensive. Nonetheless, case 1 only partly explains why wastewater reuse is so limited in countries and locations experiencing water deficits. After all, users rarely if ever pay the full cost of water supply. Governments in the MENA region and throughout the world have shown that they are willing to subsidize these services for key sectors such as the urban poor and irrigators. It would then seem that requiring payment of full costs for recycled wastewater would be both unreasonable and exceptional.

3.3 Case 2: Conditional demand for recycled water is too low → Limited reuse may be possible

It is often tempting to think that reuse can solve or at least alleviate water shortage problems simply because there is excess demand (among one or both of the low- and high-value users) at the prevailing prices for water, and because the theoretical quantity of reused water is large enough to make up some portion of this deficit. All that is needed is additional subsidy to facilitate reuse, which is in some sense just an extension of the policies that maintain low water prices.

There is an important flaw in this reasoning. When the price for conventional water is artificially kept low and does not reflect its scarcity value, what becomes relevant is the demand for reused water conditional on those prevailing prices. Because this demand is suppressed by existing low water rates, it is often the case that the effect of reuse on lessening the shortage will be minor, as in case 2. This may be particularly true when the specific water units foregone by users due to water scarcity are also the units for which reuse demand is below the existing price. In other words, consumers will continue to not consume those units because the wastewater alternative is not perceived to be good enough to justify its purchase. High-value users may be especially sensitive to quality differences. Furthermore, consumers in developing countries are often used to coping with unreliable water supplies, and are often able to maximize consumer surplus by switching among water supplies. Real world evidence for these behaviors and preferences (including willingness to pay for reuse) will be discussed in section 4.

Under such conditions, and if conventional and recycled water sources are kept separate, additional subsidies will be necessary to achieve reuse goals and to drive the price of recycled water below that of conventional water. Such policies, which have only achieved marginal success in countries such as Tunisia, will further increase the difficulty of recovering the costs of reuse systems, and could impose real economic costs on society (as shown in the Appendix). If we consider that prevailing prices are generally already below the cost of supplying water from relatively high quality sources, it is easy to understand why reuse may have a steep road to climb.

3.4 Case 3: Recycled water is mixed with conventional supplies → Reuse is likely

The most obvious solution to the problem of differentiated and suppressed demand for recycled wastewater is to eliminate user choice with respect to water sourcing. Case 3 represents one such strategy: in this situation, adequately treated wastewater is released and mixed directly into conventional surface water supplies (rivers, surface water reservoirs, or groundwater, via targeted recharge). Water suppliers then collect and distribute water tapped from this augmented volume of water. The incremental cost of adopting this approach varies from a cost of nearly zero, if sewerage and treatment are already in place and treatment facilities are located next to the discharge sites, up to the cost of sewerage and treatment plus

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6 There are of course exceptions, but they seem to be for very special cases and depend on creative institutional arrangements, for example the case of irrigation of a golf course in Benslimane, Morocco (Lahlou 2005).

disposal, when these are not present and discharge sites are far away. Some of the MENA countries with the most successful reuse policies, for example Jordan, pursue this type of re-mixing strategy.

One issue that arises with this strategy is that the demand for this type of mixed water may decrease somewhat, if water users, and especially high-value users, perceive a degradation in quality due to the mixing. This effect will be particularly acute when treatment is inadequate. The cost to municipal and industrial users may also increase since additional treatment, or a shift to more expensive alternatives like desalination or deep aquifers, may be necessary to achieve water quality standards in certain sectors. Taken to the extreme, specific types of industries requiring highly treated water might not locate in locations where source water quality is judged to be poor. The reduced demand for mixed water is reflected in debates over how reuse affects crop yields and the export potential of the agricultural sector, since export markets for high-value fruits and vegetables may not accommodate potentially contaminated crops. To be sure, the agricultural sector in Jordan has been affected by this debate (Mrayyan 2005; Pasch and Macy 2005).

3.5 Case 4: Separate provision of recycled water to specific user types → Extensive reuse may be possible

Case 4 represents a second strategy for solving the excess demand problem. In this situation, high-value uses are protected and continue to receive water from the conventional supply at the standard tariff. Mixing wastewater effluents into conventional sources is limited by a policy that is geared towards differentiated water delivery.[7] Recycled, adequately-treated wastewater is then delivered to the systems supplying low-value users, via connections to existing conveyance networks or targeted recharge of source waters that serve those systems exclusively. This type of targeting has been applied successfully in Israel and in the richer Gulf states, where wastewater treatment is already very high.

Assuming that demand decreases somewhat given concerns over quality, a targeted reuse policy will typically increase water consumption and augment water supplies unless the low-value user's demand for recycled water is also much lower than it is for the conventional source. In contrast to case 2, the low-value user in this situation is unable to choose unmixed conventional water. What conventional water remains from high-value uses could be mixed into the recycled water provided to the low-value user by the water resources planner, but this water would not be supplied separately.

3.6 Efficiency implications of successful wastewater reuse policies

Regardless of whether they work or not, an important question is whether the approaches to reuse described in cases 3 and 4 actually deliver net economic benefits to the societies they serve; i.e. whether they are efficient relative to the status quo. Under the existing political economy of water supply in many MENA countries, with highly subsidized water rates, there is reason to be doubtful about this prospect. It may be the case that water shortages actually serve to reduce welfare losses since the units foregone by consumers may be among the ones for which supply costs already exceed benefits.

The efficiency implications of wastewater reuse depend on the following set of factors:

1. The gap between price and supply cost (i.e. the size of the water subsidies);

7As a practical matter, it will always be difficult, if not impossible, to eliminate all mixing between wastewater and "conventional" water supplies. In most cases it is much easier and less costly to discharge treated effluents into the environment, such that they will end up in surface waters or will add to natural groundwater recharge. Mixing and flow downstream (case 3) is in fact the norm for point sources of wastewater in industrialized countries that achieve full treatment.

2. The price elasticity of the demand curves (i.e. the extent to which these subsidies result in inefficient allocation of water resources);
3. The extent to which the supply constraint prevents high-value uses of water, either when the scarcity value of water is very high and alternatives are expensive, or when low-value uses are protected by property rights; and
4. The extent to which a push towards reuse can lead to socially beneficial, but currently undersupplied, investments in sanitation and wastewater treatment.

Implementing a wastewater reuse policy can be considered to have three separate effects which can potentially decrease welfare. The first is a demand effect. As explained above, a drop in perceived quality, experienced by users in cases 3 and 4, likely decreases water demand, such that the consumer surplus on all units originally consumed under the "no reuse" policy is negative. The second effect is a supply expansion effect, which allows consumption of low-value units further along the demand curve. This expansion effect will have a negative welfare impact when water is priced far below the full supply cost, which is the norm rather than the exception in most developing countries and the MENA region (see discussion in section 4). The third effect is the effect of reuse cost. If there are additional costs associated with collection, treatment, or disposal of recycled water into receiving waters, the net loss on all units consumed beyond the original supply constraint, and below this higher supply cost, will also increase by this incremental amount.

There is another potential problem associated with subsidizing conventional water supply alongside promotion of subsidized reuse. Insufficient funding for collection and treatment of domestic and industrial wastewater can lead to deterioration of water networks over time, increasing pollution of receiving water bodies, which can in turn further reduce the demand for water (Myers and Kent 1998). "Unplanned" reuse and pollution could therefore conceivably reduce the quantity of water that is consumed below the original supply constraint, and thus intensify water scarcity. In this case, the demand effect of welfare losses will be particularly large, even without considering the ecological costs imposed by inadequate treatment of wastewater.

For these reasons, greater reuse will often result in net welfare losses. But whether or not efficiency suffers will in reality depend on the gap between price and supply cost (i.e. the size of the water subsidies) and the price elasticity of the demand curves (i.e. the extent to which these subsidies result in inefficient allocation of water resources). It is not hard to imagine situations in which wastewater recycling might increase social welfare; these are depicted in Figure 2.

The simplest case that may lead to welfare improvements is when supplies are so tight, overall or just among a subset of high-value users, that the scarcity value of water rises above the full cost of supplying recycled water, such that relaxing the supply constraint inevitably leads to welfare gains.[8] This may result when there is extreme water stress (Panel A) or when low-demand users are upstream of the others in terms of location or rights q_l, and are thus able to capture most of the available water at prevailing tariff rates, creating large inefficiencies (Panel B; as shown downstream users have rights of only q_h). Both of these situations can lead to gains even when the cost of reuse is higher than the cost of the fully-utilized conventional supplies. In the first instance, the welfare gains from expanded reuse are depicted by area A. In the second instance, there are major foregone benefits for the high-value user consuming at level q_h. Society could invest in desalination at cost c_d and still experience small gains. But additional investment in wastewater reuse would offer much larger benefits, depicted by area A.

8 Of course, there may still be net losses even when the scarcity value is high, if relaxing the supply constraint leads to consumption of much more water below the cost of supply.

The third situation in which welfare gains are possible from reuse corresponds to a case in which the net social cost of recycling water is lower than the cost of conventional supplies (i.e. c_r lies below c_c), such that the economic loss imposed by subsidy pricing could be reduced (Panel C). Such conditions are probably unlikely in MENA, because sewerage and full wastewater treatment of water is typically low, and because the systems collecting wastewater are seldom linked with water supply systems that could use recycled water. Still, they could occur where comparatively more expensive investments in desalination can be avoided, for example in the higher-income Gulf States. The fourth and final condition that could deliver welfare gains is one in which the social benefits of expanded wastewater collection and treatment outweigh their costs, such that joint reuse and wastewater projects allow the capture of significant positive externalities (Panel D). As MENA countries continue to develop economically, it seems likely that more and more locations will find improved wastewater management to be an attractive proposition. And though this paper does not address the economics of wastewater treatment in MENA, it may also be that many countries have not thus far invested in wastewater management at the socially efficient level. Indeed, several MENA countries are now aggressively pursuing wastewater improvements, most notably Morocco.

In all four cases, the higher cost incurred for reuse (relative to the prevailing price p_2*) does imply welfare losses on all units consumed beyond the point where marginal benefits are equal to c_r; these are shown by area B. Whether area B is larger than area A will depend on the shape of the demand curves and the premium that must be paid to safely recycle water.

These four situations may actually apply to varying degrees in MENA countries where water scarcity is acute and current water policy protects low-value users. In most MENA countries, as shown in Figure 3, the agriculture sector is the largest water user, in large part owing to low or zero water rates for irrigators (see next section). But while there may be some potential for economic gains among small groups of high value water users, such gains should not be overstated.

4. Analysis of Reuse Constraints and Realities in the MENA Region

Having described the series of cases under which wastewater reuse may be considered to alleviate water scarcity problems, we now turn to some of the realities facing MENA countries and governments seeking to promote this concept. We begin with an assessment of the tariff structures for agricultural and municipal water users in the region. These are illuminating because they largely confirm the claim made in section 3 that low water fees are almost ubiquitous in MENA, such that the gap between water prices and the cost of delivery is quite large, particularly in the low-value agricultural sector. We then consider more carefully evidence on the demand for recycled water, discussing evidence on crop yields from irrigation with conventional versus reused water, the prices being levied for recycled water relative to conventional sources, and finally discussing insights obtained from willingness-to-pay and other preference surveys. These forms of evidence help form a crude typology of MENA countries according to where they fall with regards to the reuse policy cases 2 through 4 developed in section 3.

4.1 Water tariffs in MENA countries

There are limited centralized databases for information on water tariffs across countries;[9] this makes it difficult to obtain reliable and up-to-date obtain information on water tariffs in MENA countries. Table 2 represents an attempt to document the range of prices being charged for irrigation and domestic water (columns 2 and 3), as well as an estimate of the

9 The most complete may be the annual tariff survey put out by Global Water Intelligence; refer to: http://www.globalwaterintel.com

marginal cost of raw water supply (column 4), which generally includes the costs of maintaining storage and conveyance infrastructures. This marginal cost does not include either the cost of capital depreciation or for treatment to make water potable, and of subsequent distribution systems for municipal and industrial users.

Fees levied to irrigators for agriculture are very low and sometimes even zero. In the MENA countries with the largest surface water irrigation systems (Egypt, Iran, Lebanon, Morocco and Syria), charges vary from annual land levies (in Egypt, Lebanon and Syria), where the price of marginal units consumed is zero, to a fraction of the water supply cost (in Morocco and Iran). For groundwater, farmers typically pay their own pumping costs (typically up to about US$0.20/$m^3$) but nothing more. In addition, MENA governments have in the past provided generous subsidies for installation of groundwater pumping equipment, and fuel subsidies are common (Bucknall et al. 2007). These policies do little to encourage water conservation, which could itself go a long way towards relieving water shortages. Only Israel implements a water management policy that charges farmers anything close to the full cost of supply, and it is also one of the only governments in the region to monitor and meter groundwater abstractions, charging the same rate as for surface water uses. No MENA countries use scarcity pricing even though water scarcity is supposedly acute. Thus, it seems that reuse could potentially compete with groundwater pumping if it were dependable and of sufficient quality, but it is unlikely that irrigators would opt for recycled water over conventional surface supplies if they had any choice, given the low water rates in MENA countries.

On the other hand, domestic and municipal water users in some MENA countries do pay tariffs that begin to approach the costs of supply and treatment to drinking water standards. As documented in the various sources listed in Table 2, increasing block tariffs with lifeline rates are common, so it is not possible to determine average prices paid by these users without information on average consumption, which is not easily obtained. Nonetheless, it seems to be the case that nearly full cost recovery is achieved by municipal piped water systems in Israel, Jordan, Oman, and the United Arab Emirates (the latter two make extensive use of desalination), which have average tariffs ranging from $0.70-1.30/$m^3$. Utilities in Tunisia, Morocco, Kuwait, Algeria and Lebanon also recover a large proportion of their operating costs through tariff revenue. In theory, higher rates could facilitate the implementation of recycling for augmenting municipal water supply. But these high-value users are also the ones most concerned about quality differences between conventional and reused water, so the reduced price-cost gap for municipal users is not particularly helpful in promoting reuse.

It is also true that some MENA countries charge among the lowest rates for municipal water in the world, for example Saudi Arabia, Egypt, Libya, Qatar and Yemen. Additional and separate charges for wastewater management are relatively rare in the region and usually do not come close to the full costs of sewerage and treatment documented in section 2. Wastewater tariffs in some major MENA cities are compared with water supply tariffs in **Error! Reference source not found.** (Global Water Intelligence 2010). Only in Dubai and Jerusalem, and perhaps Tel Aviv and Ramallah, do the combined tariffs appear to come close to the total combined costs of high quality services. Collectively, these data go a long way towards explaining why sewerage and wastewater treatment rates are so low in MENA (recall the data from Table 1). Increasing rates is not impossible; it is hardly a coincidence that the recent rise in tariffs in the large Moroccan cities has coincided with a large push to improve wastewater management, and further rate hikes are anticipated to sustain this progress.

If we relate the realities of these pricing systems to the conceptual models developed in the previous section, we would conclude that the cost of safe, planned reuse in most locations in

MENA will today far exceed the cost of conventional supplies, because it requires investment in sewerage and treatment services that are partial or do not exist. While such investments may be justified from a social welfare perspective if for example improved wastewater management delivers net benefits, the public sector burden it would impose (given prevailing tariffs) means that financing and sustaining these new systems would be quite a challenge. Improving existing wastewater management could more than double the financial cost of reuse relative to conventional supplies. Thus, aside from the possibility that the provision of sanitation and wastewater treatment may be too low in MENA, which this paper does not address, it appears that the welfare-improving conditions for reuse described at the end of section 3 do not apply widely.

4.2 The demand for conventional water versus recycled wastewater

One source of information on how irrigators might perceive the recycling of used water comes from farm productivity data. Many supporters of reuse suggest that crop yields can be improved, owing to the nutrients present in recycled water, or at least that fertilizer costs can be decreased (Benabdallah 2003). However, the Drainage Water and Irrigation Project (DWIP) in Egypt has produced data related to the use of for three types of water—fresh surface water, water that is a mixture of surface and reused water (from upstream irrigated areas as well as municipal discharges), and pure reuse of drainage water—that paints a different picture (soil fertility and climate).

). Of course, in Egypt it is true that much wastewater is simply released untreated into irrigation systems, and the damages from reusing "treated" water would perhaps not be the same. Data such as that presented in soil fertility and climate).

should also be interpreted with caution for other reasons. It could be that the farms irrigated with mixed or drainage water are different from those with access to fresh water sources along other dimensions that are important in determining crop yields (such as farmer effort, use of inputs like labor and fertilizers, soil fertility and climate).

There is however robust evidence that suggests that the demand for reclaimed wastewater is generally lower than it is for alternative sources of fresh water. The first source of evidence is in the fees charged for reused water (summarized in Table 2). Yemen and Syria do not charge farmers anything for recycled water (Bazza 2003; Baquhaizel and Mlkat 2006); prices in Kuwait are also very low (US$0.07/m^3) relative to the cost of supply (Fadlelmawla 2009). The Tunisian experience with wastewater reuse offers an especially cautionary story in this sense. There, the government has mandated a price of US$0.02/m^3 for farmers using recycled wastewater, in an effort to stimulate reuse (Lahlou 2005; WHO 2005). This price is only a fraction of the US$0.07/m^3 price for already heavily-subsidized irrigation water, and yet some farmers continue to show reluctance to use this alternative water (Bahri and Brissaud 1996; Shetty 2004; Boubaker 2007). We can conclude that the demand for recycled water, conditional on low prevailing prices for conventional water, is extremely low in Tunisia. Only in Morocco is there a single pilot case of pricing of recycled water at close to the marginal cost of supply, for irrigation of a golf course for which the alternative of municipal drinking water is much more costly (Lahlou 2005).[10]

Preference studies confirm that perceptions of quality are important. Evidence from contingent valuation and other studies suggests that users are often willing to pay a premium for high-quality water and sanitation. In one Kuwaiti study, households were willing to pay

10More generally, the availability of high quality alternatives, and thus the concept of the conditional demand curve discussed in section 3, is very important. Tunisian farmers who have no choice between using reclaimed wastewater and using high salinity groundwater express little opposition to paying for reuse (Shetty 2004); Palestinian farmers facing acute water scarcity also have favorable impressions of reuse (Khateeb 2001).

more for domestic water supply if they were assured that it did not contain recycled water (Dolnicar and Saunders 2006). Studies in Qatar and Jordan have found that households express concern over reuse that is used for growing agricultural products (Ahmad 1991; Mrayyan 2005; Pasch and Macy 2005). In Crete, forty percent of farmers are not willing to pay anything for recycled water and only 18% of farmers are willing to pay as much for it as for fresh water (average WTP is about 55% of the prevailing rate for conventional water) (Menegaki et al. 2007). One alternative that is sometimes advanced for cheaper wastewater reuse, which is to provide only basic treatment, is not viewed favorably by farmers because it precludes certain uses and involves crop restrictions. Nearly half the farmers in Jordan and Tunisia say they would not be willing to pay anything for such water (Madi and Braadbaart 2002).

At the same time, there is also dissatisfaction with the existing quality of water and sanitation services in some MENA countries, and a general willingness to pay more for improvements. In Palestine, 83% of respondents from five Gaza governorates were willing to pay increased fees for services that met the WHO standards for water quality (Al-Ghuraiz and Enshassi 2005). Average WTP was about US$0.64 /$m^3$ for higher-quality services, close to an estimate of the cost of such services, and much more than actual average payments of \$0.23/m^3 (LEKA 1997). These data from relatively poor communities support the idea that wastewater management may be underprovided in many MENA countries.

4.3 Relevance of these factors to the reuse situation in MENA countries

Based on these realities, this section closes with the following list of general observations about the context of wastewater reuse in MENA countries, and a typology grouping countries according to the policy cases developed in section 3 (**Error! Reference source not found.**). First, it seems that few countries in MENA charge anything close to the full cost of piped water supply, and there is no scarcity pricing even in countries with full cost recovery. Thus, when source choice is preserved (cases 1 and 2), the relevant concept of demand for reuse is the conditional demand curve, given the low prevailing price for conventional sources.

Second, as we have seen, there is evidence from several countries that conditional demand for recycled water is very low. As long as users have a choice between conventional and recycled water, it will be hard to achieve extensive reuse, since users will continue to attempt to use conventional sources unless very large subsidies are given to users of recycled wastewater. The economics of case 2 are unlikely to look favorable as long as water rates remain so far below the cost and/or scarcity value of water.

Third, in most MENA countries, sewerage and wastewater treatment are currently limited, so the costs to achieve safe, planned reuse are likely to be considerably higher than the cost of conventional supply. Under the existing political economy of water supply, wastewater reuse is likely to impose net welfare costs on society, except where it displaces more expensive desalination options, where non-negotiable (and non-tradable) water rights impose very high costs on high-value users (at the benefit of low-value users), or where the costs of improper wastewater disposal are sufficiently high. Of course, if this last condition holds, investment in improved wastewater management should be pursued even without reuse.

Fourth, cost recovery appears to be even lower in the wastewater management sector than it is for the supply of irrigation and drinking water, so there is a tendency for treatment systems to be poorly operated and maintained. This leads to widespread unplanned reuse (for example in Egypt and Syria), which reinforces perceptions that recycled water is low in quality and should be provided to users free of charge or at very low prices. Water availability also decreases as pollution increases, which increases apparent scarcity, since there is little demand for highly contaminated water.

In general, we can consider that most MENA countries can be grouped as falling under case 2. These countries tend to have low water rates, particularly for irrigators, and, with a few exceptions, relatively limited wastewater treatment. Jordan, with its fairly well-developed wastewater collection and treatment infrastructure, pursues the most active re-mixing strategy for wastewater recycling. If the case 2 countries were to achieve higher levels of wastewater treatment, they could presumably pursue a similar remixing strategy with some degree of success, though the gains would likely be limited due to persistent concerns over quality. Indeed, the overall water balance under case 3 might improve only marginally since re-mixing of untreated wastewater ("unplanned" reuse) in these countries already occurs to some extent, particularly in Egypt, Syria, Morocco and Yemen. Israel also does some re-mixing, but tends to favor more targeted reuse (case 4), as do the richer Gulf States. Tunisia manages only limited, targeted reuse, in large part because the pricing of water and demand for reused water are not favorable to widespread reuse. In case 4 countries, irrigators and urban landscapers are the targets for most reused water.

5. Policy Recommendations

Working from these observations, it is possible to offer several recommendations for improving the potential of wastewater reuse in MENA countries.

First, reuse policy at the strategic, national level has an important role to play. A policy of remixing treated water into conventional supplies (as is practiced in Jordan) or supplying low-value users in the agricultural sector exclusively with recycled or mixed water (as done in Israel and in many Gulf countries) is more likely to be successful than one which preserves user choices with respect to sourcing of water. The availability of alternatives is an important factor in reducing demand for recycled water.

Second, countries that have achieved complete or near complete cost recovery in water supply and wastewater management (Israel, the UAE, Oman, Jordan to some extent, and increasingly, Morocco) are better positioned to leverage the potential of reuse, because they have already internalized these costs. Under these conditions, reuse should be aggressively pursued using one of the strategies listed above, as it will certainly be cheaper than desalination, and may lead to general improvements in welfare as the scarcity value of water rises above the incremental cost of reuse.

Third, before wastewater reuse can really take off, there is an urgent need for MENA governments to solve the free-riding problems in the wastewater collection and treatment sector. Inadequate upstream sanitation which leads to pollution of water resources (a local public good), imposes very large costs on downstream communities in MENA countries. Upstream users have little incentive to pay for sewerage and treatment consisting of anything more than removal of waste from the local neighborhood, but governments should work to improve understanding of these technologies' costs and benefits from a wider perspective. Indeed, it is likely that the social optimum in many MENA countries involves much higher levels of wastewater treatment, although more research and valuation work is warranted to better understand the benefits it would provide. As long as government regulators and institutions allow upstream users to pollute water resources at little to no cost, however, the existing situation will persist; expecting wastewater reuse to solve this problem is unrealistic because it does not address the underlying problems with incentives.

Finally, in countries that provide large subsidies to users of water and sanitation services, the promotion of reuse alone may actually decrease social welfare, given the inefficiencies associated with overuse of water at low prices. It may also exacerbate water quality and scarcity problems due to poor operation and maintenance of infrastructures and increased discharges of untreated wastewater. In these types of countries, targeted opportunities for wastewater reuse probably exist, especially if low value users' water rights are protected and impose high costs on higher-value users. But a national policy to stimulate reuse is likely to face practical resistance from users and financial difficulties due to insufficient funds to provide the subsidies needed to stimulate demand. Such countries, which often strive to achieve equity objectives by promoting low water rates, should carefully consider that improved cost recovery and efficiency in the water sector would promote conservation and likely be highly effective for enhancing social welfare. Water tariff reform can lead to greater infrastructure investment and reduced wastage, and it need not create hardship for the poor if appropriate tariff structures and/or cross-subsidies can be developed.

6. Conclusions

Previous research has shown that a variety of constraints inhibit greater formal reuse of wastewater in the MENA region. These include problems related to the incentives for reuse, including the high costs and low baseline levels of wastewater treatment, problems associated with reduced demand for reclaimed wastewater, the widespread lack of effective price signals and cost recovery in the water sector, and challenges in structuring the financing of reuse when its incremental costs are high. This paper has explored some of these incentive problems by using simple, conceptual models with two types of water consumers, and then relating these to country-specific data on wastewater coverage and water prices.

Some of the key constraints that inhibit more widespread wastewater reuse have been identified in this paper, and a number of actions that countries can pursue to improve its prospects have been proposed. These include improving cost recovery by raising water tariffs, extending wastewater management and treatment services, and pursuing targeted or national reuse opportunities that are appropriate given the existing levels of development and sustainability in the sector. National policies for reuse will do little good as long as economic incentives and financing constraints are aligned against them.

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Figure 1: Demand for Raw Water from the Natural Environment (The Conventional Source) for Two Users, One High-Value and the Other Low-Value

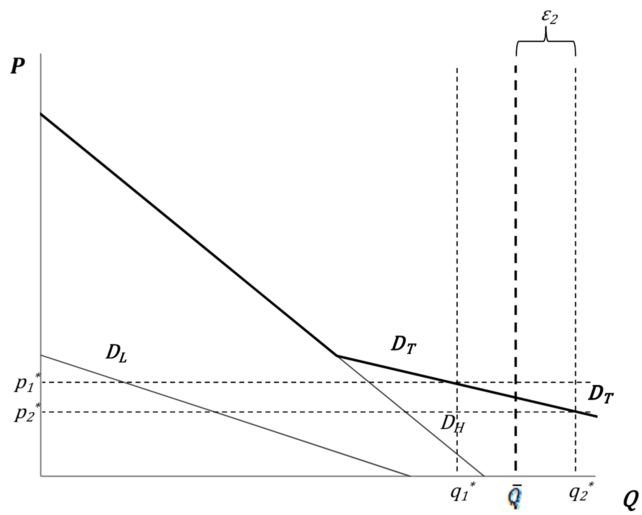
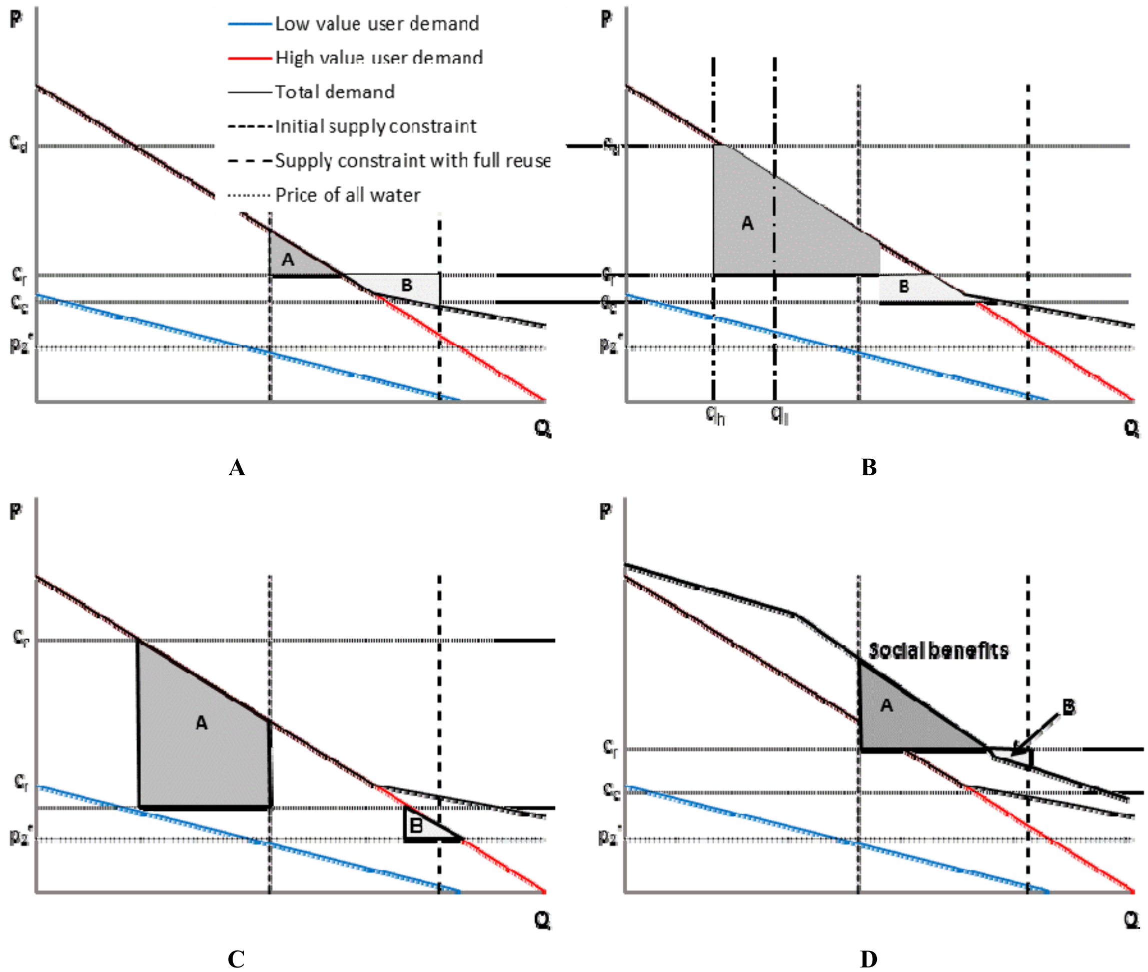


Figure 2: Four situations in which reuse can lead to welfare gains, in spite of low prevailing water tariffs



A B C D

Notes: Panel A: scarcity value of water exceeds cost of supply; Panel B: quotas or water rights inefficiently protect low-value uses; Panel C: reuse is much cheaper than conventional supply; and Panel D: reuse delivers positive externalities by fostering better management of wastewater, as shown by the social benefits curve. In all cases, net gains are shown by area A, net losses are shown in area B.

Figure 3: Water Consumption by Sector in MENA Countries (Latest Data from FAO Aquastat Database)

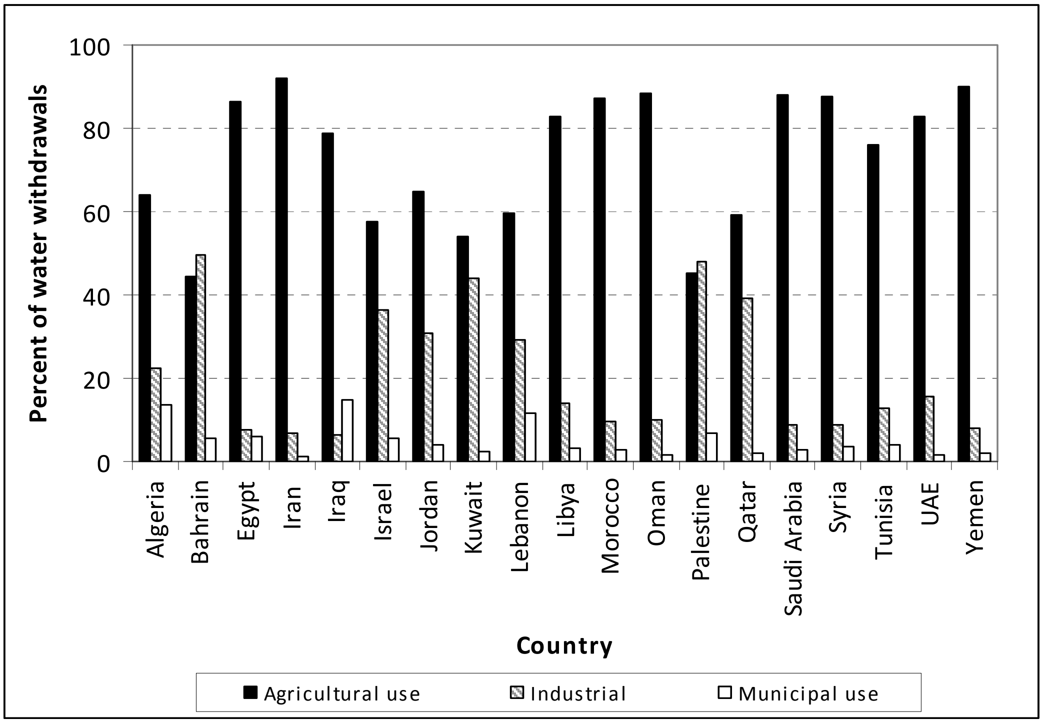


Table 1: Sewerage Coverage in Urban and Rural Areas, and Wastewater Treatment and Reuse Rates in the Middle East and North Africa

Country	Sewerage rate to piped network (% of households connected) A. Urban	B. Rural	C. Overall	D. Treatment rate (% of collected wastewater by volume)	E. Treatment rate (Est. % of wastewater by volume)[a]	F. Reuse efficiency (% of treated wastewater by volume)	G. WRI (Est. % of all wastewater by volume)[a]
Algeria	92	50	77	73	56	Na	Na
Bahrain	Na	Na	77	100	77	16-20	14
Egypt	74	18	42	79	33	24	9
Iran	17	0.2	11	4	0.4	Na	Na
Iraq	37	2.4	25	Na		Na	Na
Israel	100	Na	92-95	63	60	99	59
Jordan	67	5.9	54	88	47	76	39
Kuwait	Na	Na	>99	100	99	63	63
Lebanon	100	22	89	2	2	50	1
Libya	54	54	54	7	4	100	5
Morocco	86 (old data)	3.3 (old data)	73	20	3	6	0
Oman	90	51	79	34	27	66	23
Palestine	57	7	43	Na		Na	Na
Qatar	Na	Na	78	100	78	50	44
Saudi Arabia	44	0	35	75	26	40	12
Syria	96	45	72	40	29	78	27
Tunisia	79	8.9	54	79	43	20	11
UAE	93	63	87	Na	87	25	25
Yemen	42	0.4	12	62	8	40	11

Notes: Na: Data not available; [a] Estimate only since the sewerage rate does not correspond to the volume collected but rather to the % of households connected. WRI = Wastewater Reuse Index.

Sources: Author's calculations using data from Aquastat database (FAO 2010), Kfouri et al. (2009), Jimenez and Asano (2008), Global Water Intelligence 2010 (http://www.globalwaterintel.com), and country reports from the JMP (World Health Organization and UNICEF 2010).

Table 2: Costs of Wastewater Collection, Treatment, and Reuse

Component	Cost/m^3 (US$)	Notes	References
Conveyance to treatment works	0.30–0.80		Whittington et al. (2009)
Non-mechanized secondary treatment	0.10–0.22	Necessary for restricted reuse	WHO (2005), Shelef et al. (1996), Haruvy (1997), Amami (2005)
Aerated secondary treatment/activated sludge	0.22–0.27	Lower land requirement	Kamizoulis et al. (2003), Shelef et al. (1996), Shelef (1991), Haruvy (1997)
Tertiary treatment (in addition to secondary)	0.07–0.18	Necessary for unrestricted reuse	Shelef et al. (1996), Haruvy (1997), Shelef et al.(1994)
Distribution	0.05–0.36		Shelef et al.(1994)
Total	0.16–1.15	Treatment and conveyance	Shelef et al. (1994), Lee et al. (2001), Whittington et al. (2009)

Table 2: Range of User Fees for Water from Conventional and Reuse Sources for Irrigators, and for Domestic Users

Country	Conventional water tariff ($/m^3, unless otherwise noted)	Domestic water tariff [a] ($/m^3)	Marginal cost of raw water supply ($/m^3)	Recycled water tariff ($/m^3)	Original Sources for data
Algeria	0.03	0.16, 0.52 (Average = 0.5)	0.26	Na	Laoubi & Yamao (2008); Maliki et al. (2009)
Bahrain	Pumping cost only (0.01-0.23)	0.07, 0.22	Pumping cost	Na	FAO (1997); Qamber (2003); Basheer et al. (2003)
Egypt	Na; Annual land tax (About $3/fed-yr)	0.04	Na	Na	Bazza & Ahmad (2002); Malashkhia (2003); Kebiri (2010)
Iran	0.04 (12% supply cost)	0.06 (Country average)	0.32	Na	Moghaddasi et al. (2009)
Iraq	(5-12% supply cost)	0.01	Na	Na	Razzaq (2010)
Israel	0.18-0.29	1.04 (2010 average)	0.27	No difference	Becker (2002); Markou & Stavri (2005); Global Water Intelligence (2009)
Jordan	0.01-0.05 (Avg = 0.03) (annual fees by area of planted crops)	0.7	0.32	No difference	Bazza & Ahmad (2002); Dinar & Mody (2004); Venot et al. (2007); Arabiyat (2007); The Jordan Times (2010)
Kuwait	Pumping cost	0.58	Na	0.07	Fadlelmawla (2009); FAO (2010)
Lebanon	Na; Annual land tax ($6-330/hA-yr)	0.12-0.42	Na	Na	ESCWA & UNDP (2002)
Libya	Pumping cost only	0	Na	Na	Global Water Intelligence (2009)
Morocco	0.02-0.06 Pumping cost < 0.18	0.24-0.95	0.02-0.11	0.06 – 0.24	Bazza & Ahmad (2002); Choukr-Allah & Hamdy (2008), Benabderrazik & Doukkali (2003)
Oman	Pumping cost	1.3	Na	Na	FAO (1997); Omezzine & Zaibet (1998)
Palestine	Na	0.23	Na	Na	Al-Ghuraiz & Enshassi (2005)
Qatar	Pumping cost	No charges for nationals	Na	Na	FAO (1997)
Saudi Arabia	Pumping cost only	0.03, 0.04	Na	Na	FAO (1997); Gulf News (2010)
Syria	NA; Annual levy	0.06, 0.17	Na	0 (unplanned)	Bazza & Ahmad (2002)
Tunisia	0.07	0.3, 0.4	0.09-0.16	0.02	Dinar & Mody (2004); Easter & Liu (2005); Mourad (2010)
UAE	Pumping cost	1	Na	Na	FAO (1997)
Yemen	Pumping cost: 0.05-0.2	0.04	Pumping cost	0 (unplanned)	FAO (1997); Bazza & Ahmad (2002)

Notes: Na: Data not available (no information found). a Most countries utilize increasing block tariffs, so it is difficult to derive an average tariff without information on the consumption per household. Therefore, only the prices for the first two blocks are listed.

Table 4: Wastewater Tariffs in Select Major Cities in the MENA Region [a]

City	Piped water supply (US$/$m^3$)	Wastewater management (US$/$m^3$)
Overall average cost estimate (from Table 2 and Whittington et al. (2009))	0.35 - 0.85	0.5 - 1.3
Algiers, Algeria	0.16 - 0.52	0.03
Manama, Bahrain (2009)	0.07 – 0.22	None
Alexandria and Cairo, Egypt	0.05 – 0.07	0.02
Baghdad, Iraq (2008)	0.002 – 0.005	None
Tehran, Iran (2007)	Based on dwelling size	None
Jerusalem, Israel	1.87	Na; combined tariff
Tel Aviv, Israel	1.29 – 1.45	0.33
Amman, Jordan	0.7	Na; combined tariff
Casablanca, Morocco	0.76 – 0.80	0.19
Rabat, Morocco	0.65 – 1.85	0.18-0.32
Muscat, Oman	1.22	Na; combined tariff
Ramallah, Palestine (2009)	1.22 – 1.37	0.32
Jeddah and Riyadh, Saudi Arabia	0.03 - 0.04	None
Damascus, Syria (2009)	0.06 – 0.17	0.02
Tunis, Tunisia	0.29 - 0.39	0.09
Dubai, United Arab Emirates (2009)	2.15 – 2.50	Na, Combined tariff

Notes: Data from Global Water Intelligence (2010), converted to US$ at 2010 exchange rates. [a]Cost estimate ranges are based on high and low cost technology options discussed in Whittington et al. (2009); ranges for cities represent prices in first two consumption blocks of the increasing block tariff.

Table 3: Crop Yields in Egypt from Different Source of Irrigation Water (DWIP 1997)

	Average yield (ton/feddan)		
Crop	**Fresh water**	**Mixed water**	**Pure drainage water**
Wheat	2.8	2.4	2.0
Maize	2.0	1.9	1.8
Rice	3.5	3.0	2.1
Cotton	0.84	0.76	0.65

Table 6: Typology of MENA Countries According to Reuse Situation

	Case 2: Limited or unplanned reuse only	Case 3: Extensive mixing of recycled water	Case 4: Targeted provision of recycled water
Countries	Unplanned: Egypt, Syria, Morocco, Yemen Limited: Bahrain, Iraq (?), Iran, Lebanon, Libya, Tunisia	Jordan To a lesser degree: Israel	Israel Few schemes in Tunisia Heavily subsidized: Qatar, Kuwait, Oman, Saudi Arabia, UAE

Appendix:

Detailed graphical presentation of the cases in the conceptual model for reuse

This appendix presents additional details and graphical diagrams for the four cases explored using the static model discussed in the main body of the paper. Recall that the model included two types of agents: a high-value water user sensitive to water quality (real or perceived), who might require tertiary treatment prior to reuse, as well as a less quality-sensitive, low-value water user requiring a lower level of treatment. Four cases were analyzed and these are described in more detail in this appendix, which includes graphical presentation of their equilibrium conditions:

1. The relative price for recycled water is too high → No viable reuse;
2. The conditional demand for recycled water is too low → Limited reuse may be possible;
3. Recycled water is mixed with conventional supplies → Reuse is likely; and
4. Recycled water is supplied to specific user types via separate systems→ Extensive reuse may be possible.

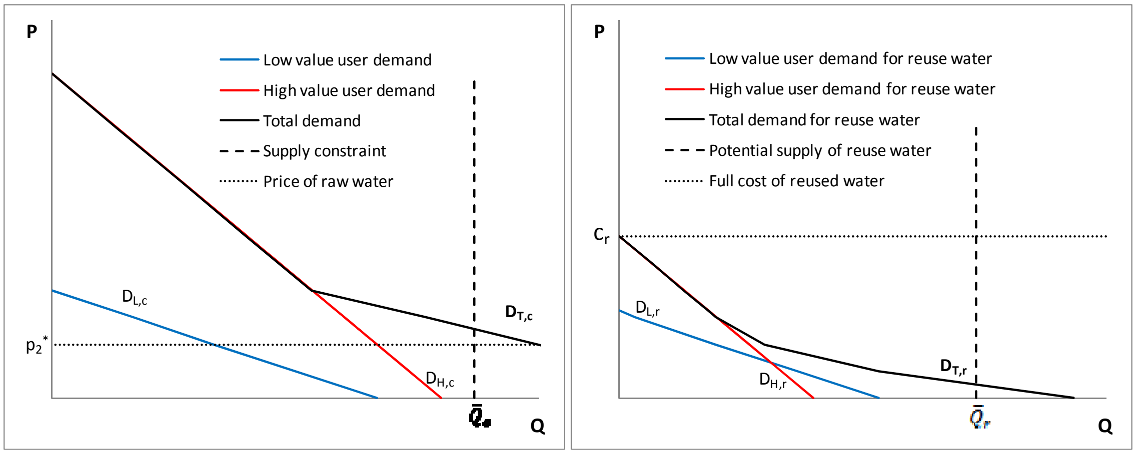
First, recall that the model assumes that users face a horizontal price curve for raw water from the conventional water supply up to the capacity limit $\bar{Q}$, after which no more water is available. The high and low-value user types have demand for water from the conventional water supply D_H and D_L, respectively, such that total demand $D_T = D_L + D_H$. If the price of raw water from conventional sources is $p_1{}^*$, the total demand is $q_1{}^*$, and there is no shortage. However, if the price of the water supplied is $p_2{}^*$, total quantity demanded $q_2{}^*$ is greater than $\bar{Q}$, and there is water shortage $\varepsilon_2 = q_2{}^* - \bar{Q}$. This situation is the typical one that motivates interest in wastewater reuse.

In what follows, it is only assumed that the total demand for recycled water $D_{T,r}(q_c, q_r)$ is lower than total demand for the conventional supply $D_{T,c}(q_c, q_r)$. This is especially the case for the high-value user— i.e. $D_{H,c}(q_c, q_r) \gg D_{H,r}(q_c, q_r)$ —due to the lower quality q_r of recycled water versus that of conventional water q_c. $D_{T,r}$ is increasing in q_r and decreasing in q_c (and the opposite is true for $D_{T,c}$), as are the demands for the low and high value users. Also, the total potential for reuse $\bar{Q}_r$ is somewhat less than $\bar{Q}_c$, since some water is lost to evapo-transpiration or infiltration during use and does not get converted to wastewater.

Case 1: Price for recycled water is too high → No viable reuse

The situation that gives rise to case 1, in which the cost of wastewater reuse confronting potential consumers exceeds their willingness to pay, is depicted in Figure A1. In this case, there is little private investment in wastewater reuse, as discussed in section 3. Figure A1 has been drawn to show a higher cost for reused water c_r than for conventional sources, but this need not be the case.

Figure A1: Case 1: No successful reuse, the cost borne by users exceeds demand among both low and high value users, in the market for recycled water (right panel). The shortfall persists at the same level $\varepsilon_2$as if there were no reuse.

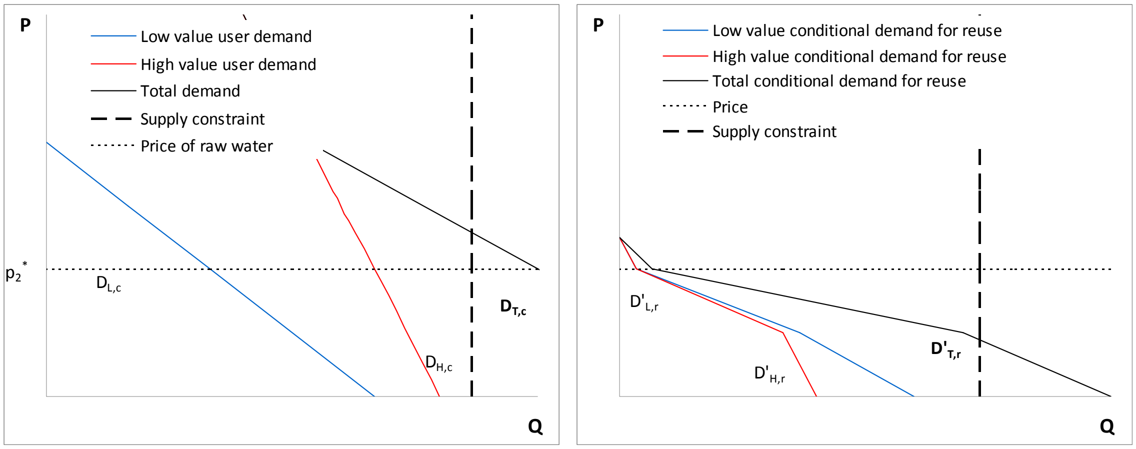


Case 2: Conditional demand for recycled water is too low → Limited reuse may be possible

Case 1 only partly explains why wastewater reuse is so limited in countries and locations experiencing water deficits, because users rarely if ever pay the full cost of water supply. Governments in the MENA region and throughout the world have shown that they are willing to subsidize these services for key sectors such as the urban poor and irrigators, so why would this be any more difficult in the context of reuse?

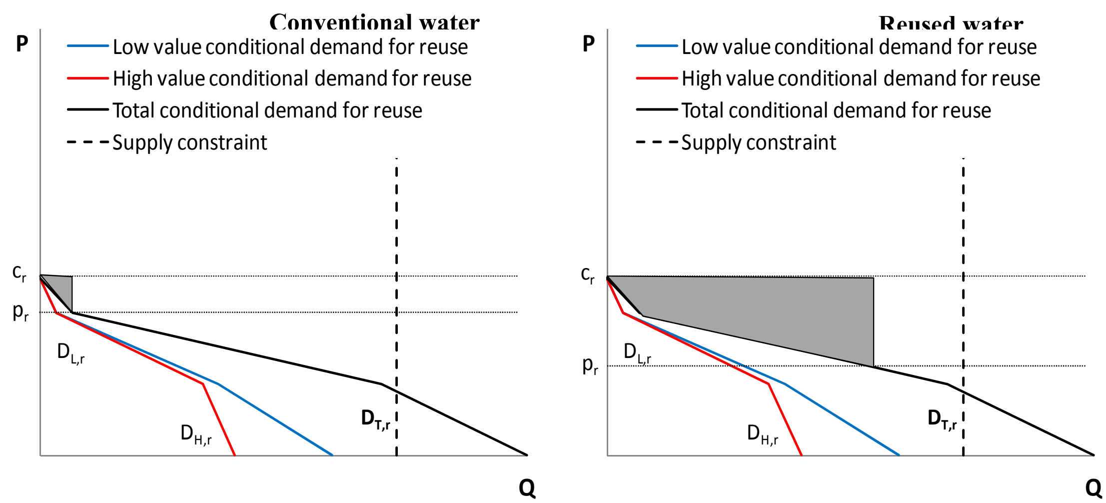
Let us imagine that the price of reused water was set at the prevailing tariff $p_2{}^*$, putting aside the question of efficiency and financing for a sustainable reuse supply. Based on the picture presented in Figure A1, one might expect that reuse would solve the shortage problem, because demand for the reused water among both low and high value users easily exceeds the amount of the shortfall at that price. However, as discussed in the paper, the relevant concept in this case is the demand for reused water conditional on the prevailing price for water from the conventional supply, which we denote by $D'_{T,r}(q_c, q_r, p_2{}^*)$. Such conditional demand curves might in fact look like the ones depicted in Figure A2, and the shortfall would not be removed by pricing recycled water at $p_2{}^*$, because consumers would forego consumption of those units due to the low quality of the wastewater alternative, which would not justify its purchase at price $p_2{}^*$.

Figure A2. Case 2: Only limited (or no) reuse is possible, demand for reused water, shown in the right side panel, conditional on the prevailing price for conventional water supply is too low to make up the original shortfall ε_2.



If additional subsidies were used to promote sufficient reuse in case 2, the perverse incentives of this subsidy pricing could impose real economic costs on society (Figure A3). In this diagram, areas in gray represent net economic losses from the expansion of reuse at subsidy prices.

Figure A3: Economic efficiency losses in case 2 if a) prevailing prices for conventional sources are also extended to recycled wastewater (left panel) and b) additional subsidies are provided to stimulate its use (right panel). Losses are shown by gray areas.

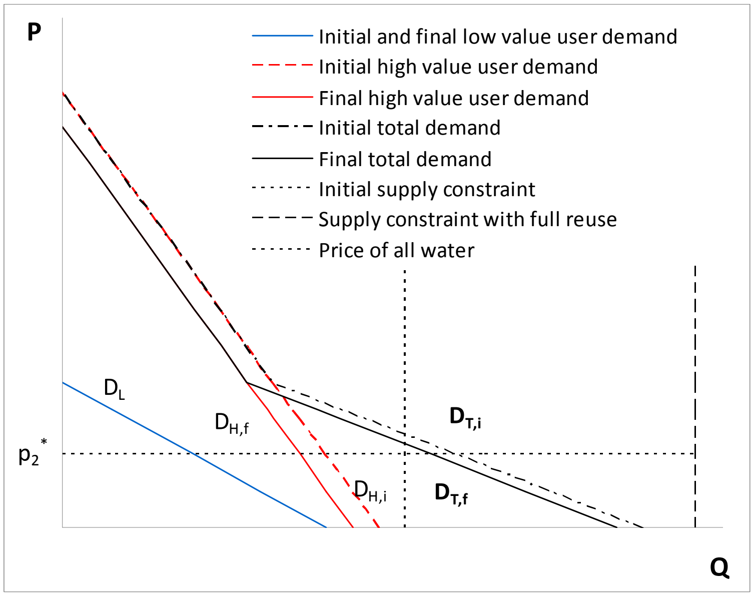


Case 3: Recycled water is mixed with conventional supplies → Reuse is likely

Case 3 represents one strategy for eliminating the problems of low demand and high cost associated with preserving users choices with respect to sourcing of recycled water: in this situation, adequately treated wastewater is released directly and mixed into conventional surface water supplies. Water suppliers then collect and distribute water tapped from this augmented volume of water.

Let us again consider this case with the help of graphical diagrams. First, if water users, perhaps particularly high value users, perceive a degradation in quality due to the mixing, demand for water may decrease somewhat, from $D_{H,i}$ for the high value user and $D_{T,i}$ overall to $D_{H,f}$ and $D_{T,f}$ (Figure A4). The behaviors that might result from this reduction in water quality have been discussed in the paper, here we focus on its effects on the market for the mixed water. From the perspective of economic efficiency, it is quite possible that reuse will result in net welfare losses, as shown in Figure A5.

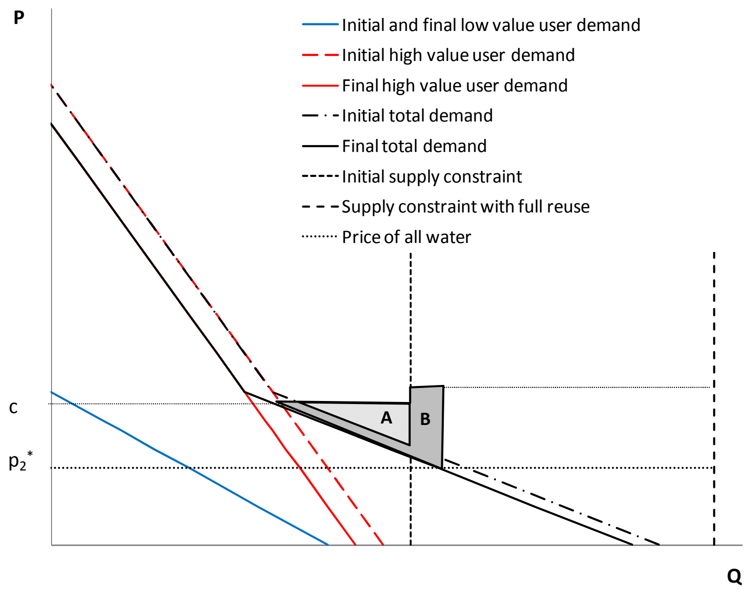
Figure A4: Case 3: Mixing of recycled wastewater with conventional sources generally makes reuse possible; some demands may decrease due to perceived drop in quality but the shortfall ε_2 is eliminated.



In this case, the inefficiency under the status quo without mixing (area A) corresponds to that part of the supply-demand relationship where the full costs of supply *c* exceed economic benefits. As shown, even without scarcity pricing, the apparent water shortage actually serves to reduce welfare losses since units not being consumed are the ones for which supply costs already exceed benefits. Implementing a wastewater reuse policy then has three effects, all of which may increase the welfare losses shown by areas A + B:

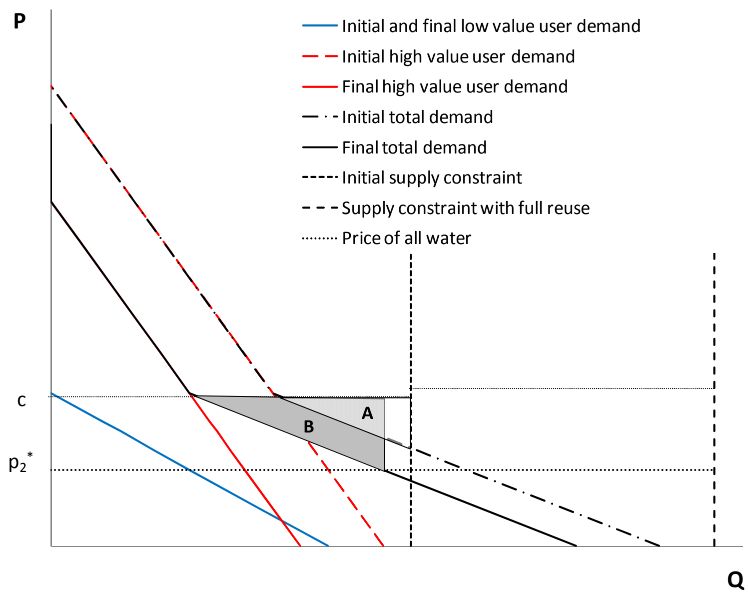
- The demand effect: As explained above, the drop in perceived quality is likely to decrease water overall demand, such that the consumer surplus on all units consumed under the status quo will be reduced.
- The supply expansion effect, which allows consumption of low-value units even further along the demand curve.
- The incremental reuse cost effect: where there are additional costs needed for collection, treatment, or disposal of wastewater into receiving waters, the net loss on units consumed beyond the original supply constraint will increase by this incremental amount (shown by the increase in cost *c* beyond the original supply constraint).

Figure A5: The efficiency cost of case 3: When the prevailing price is below the marginal cost of supply, there will be overuse of water and a net cost imposed on the economy, and planned reuse further increases inefficiency.



The particularly bad situation of degraded water quality that Myers and Kent (1998) warn against, discussed in the main paper, is further illustrated in Figure A6. This occurs when insufficiently treated recycled water heavily pollutes other sources, which leads to a strong negative demand effect, and a net reduction in the quantity of water that is consumed. Though this would seem to reduce excess demand, the apparent water scarcity confronting the affected location increases, because users can no longer access high quality water.

Figure A6. The ugly side of case 3: Insufficient cost recovery and financing in the sector may lead to unplanned reuse. Demand, particularly among high value users, may decline significantly, or the costs of supply may increase because of the need for more treatment of polluted source water.



Case 4: Separate provision of recycled water to specific user types → Extensive reuse may be possible

Case 4 consists of a strategy of using differentiated water supply to relieve the excess demand problem. In this situation, high-value uses are protected and continue to receive water from the conventional supply at the standard tariff $p_2{}^*$. Recycled, adequately-treated wastewater is then delivered to the systems supplying low-value users via connections to existing conveyance networks or targeted recharge of source waters that serve those systems exclusively.

Assuming that demand decreases somewhat given concerns over quality (Figure A7), targeted reuse will typically increase water consumption and augment water supplies unless the low-value user's demand for recycled water is also much lower than it is for the conventional source. Similarly to case 3, though, when water tariffs (shown as $p_2{}^*$) remain below the full cost of water supply, the economic efficiency of the water supply in case 4 will often suffer relative to the status quo that includes shortfalls. Losses will increase from area A only to areas A + B, because each additional unit of water consumption beyond the original supply constraint will deliver benefits that are below the supply cost. Efficiency will be worsened if the cost of reused water c_r is above the cost of conventional sources c_c, which is usually the case given that new investments will be required. The magnitude of efficiency losses will depend on the shapes of the initial and final demand curves of the user of recycled water, and on the size of the premium that must be paid for safe recycling of treated wastewater. Also, as in case 3, the risk of unsustainable reuse systems remains, such that insufficient support for highly subsidized systems may lead to contaminated water supplies that adversely affect the benefits obtained from the additional water.

Figure A7: Case 4: Differential provision of water to low and high-value users, with efficiency implications, when low-value user demand is reduced.