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Basic principles for urban water value assessment and price setting towards its full cost recovery – pinpointing the role of the water losses

V. Kanakoudis, K. Gonelas and D. Tolikas

ABSTRACT

This paper attempts to set the basic methodological framework for an integrated action plan (in terms of successive steps) to be developed that will guarantee the reliable calculation of the Full Water Cost (FWC), as defined by the WFD 2000/60/EC. Towards this goal, the crucial role of the water losses occurring in a water distribution system is demonstrated. This will help an effective and socially just water pricing policy to be developed. The cost components (direct – DC; environmental – EC; and resource – RC) comprising the FWC are analysed, introducing approaches for their reliable calculation. Regarding the DC, the marginal capacity cost and the necessary preconditions for its integration to the final water price along with its contribution towards effective water demand reduction are analysed. Regarding the EC, its dynamic character and the ways it interacts with the DC are presented. The role of the stakeholders in setting those price levels is also checked. Crucial parameters are analysed for a socially just water cost allocation to domestic users. The role of the water utility is examined, considering its responsibility in water losses. The basic policies (market-based vs. conventional) used to achieve conservative water use are evaluated. In addition, the role of the State is criticized.

Key words | full water cost assessment, water pricing, WFD

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INTRODUCTION

The European Directive WFD 2000/60/EC introduced for the first time the Full Water Cost (FWC) Recovery Principle, based on a very simple concept: any water volume outflowing from a natural resource has a negative impact on the resource's self-cleaning potential and its water balance. So, the FWC of any water volume should be calculated by considering its impacts on the initial quality and quantity of the water resource it was taken from. The FWC includes the costs required to ensure that water of proper quality is available; the price the urban user has to pay due to the reduced opportunities left to other users; and the costs for maintaining and improving the quality and quantity of the water resource based on the environmental sustainability principles (WaterStrategyMan 2002). The FWC consists of three sub-costs (direct cost – DC; environmental cost – EC; natural resource cost – RC), interlinked in various ways. These sub-costs are dynamic in nature, as they depend on various parameters. The above interconnections make the precise definition of which factors are responsible, and to what extent, for FWC recovery, a very intriguing task to achieve. The paper attempts to set the basic methodological framework and develop an integrated action plan (in terms of a flow chart), in order for the Full Water Cost (as defined by the WFD) to be reliably calculated. This will be done by considering the role of the water losses occurring in a water distribution system, and how the customers are expected to react, regarding their water demand behaviour, due to the expected growth of water rates' levels. This will then assist in

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the development of an effective and socially just water pricing policy.

The full cost of the urban water assessment process followed by its allocation to the water users is mainly based on the determination of the urban water demand curve. Until now, this process tended to neglect the fact that the major water user in an water system is the system itself, due to the water being lost through leaks and breaks occurring. There are cases where the water losses volume is more than 50% of the System Input Volume (this is very common in Greece!). Additionally the water losses rates do not have the same behaviour pattern with the actual urban water users. This happens as the leaks-related water losses greatly increase during the night due to the increased operating pressure. Exactly the opposite happens regarding the actual (mainly domestic) urban water use, where the losses are practically zero. The above-mentioned studies tend to add the leaks- and breaks-related water losses to the actual water use to form the overall water demand. This is clearly not the correct way to handle water losses.

INSIGHT ON THE FULL WATER COST COMPONENTS

The direct cost and the role of the marginal capacity cost

The direct cost (DC) includes the costs a water utility pays to provide water of sufficient quantity and appropriate quality to its customers. These costs are the Operation and Maintenance Costs (staff, energy, chemical, stock materials, fees/expenses to third parties); the Administrative and Other Costs (management related); and the Annual Equivalent Capital Costs (of new investments, depreciation of existing infrastructure). Crucial parameters affecting the level of the DC and its components concern the necessary waterworks and the way the water utility operates. The first category includes parameters related to the characteristics of: a) the water resources being used (surface or groundwater, location); b) the water-intake works (dams, drillings, floating-pumps); c) the water aqueducts (pipes, channels, tunnels, water-carrying distance); d) the water treatment plants (quality of raw water); e) the water storage tanks (location, size); and f) the water distribution network (valves, boosters, pipes). The second category includes parameters related to the way the water utility operates (e.g. continuous training of its staff to increase its productivity, speed and quality of repair and replacement works). In a water system, its capacity growth and expansion are critical aspects of its planning, since the choice of the type, timing and size of new facilities affects the level of the related DC, especially when it seems most effective for new water projects to be larger than those imposed by the current demands. What happens then is to build extra capacity to meet the increased demand. Usually this extra capacity is consumed earlier (Figure 1) due to the generated illusion of abundance. This forces the next project for even bigger capacity to start earlier than expected (Kanakoudis 2004).

This practice opposes the basic economic principle considering a project as optimal in terms of type, size and timing when it maximizes the present value of the net benefit, and not just simply balancing the costs and benefits of the investment. This directly implies that the pursuit to increase the supply to meet future demand is not rational (Griffin 2001). It is often not cost-effective to build new projects when the future demand is expected to increase at a slow pace. Early construction costs more due to initial capital commitment for a longer time and additional cost depreciation. The control efficiency of the timing stages of major new projects reveals that there are periods where the capacity of e.g. a water delivery network is less than the actual water demand. During such periods, there is an opportunity cost, the marginal capacity cost (MCC), to be considered (Griffin 2001). The costly decision to increase capacity may be delayed due to the integration of the MCC in the water price leading to a fall in demand. The problem is that the MCC changes with time. A given supplying capacity is gradually exhausted by the

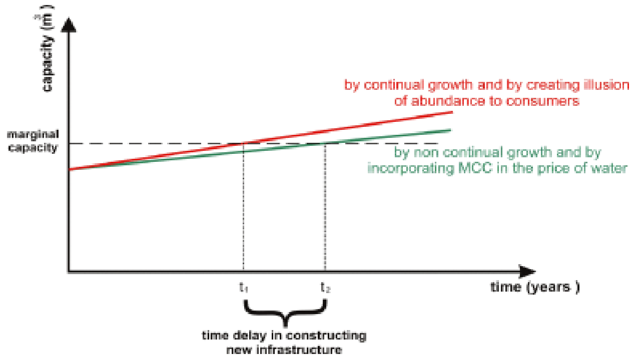

Figure 1 | Time delay in developing new infrastructure by incorporating the MCC.

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increasing demand. By the time the demand exceeds the supplying capacity the MCC begins to grow exponentially. New projects increase the supplying capacity. At that time the MCC tends to zero, and remains stable until such time as the demand growth eliminates the extra capacity (Turvey 1976). Recognition of the problem leads to regular adjustments of the water price levels due to a change in the MCC (Mann *et al.* 1980); every time the actual MCC is not included in the price, profitability is reduced (Griffin 2001). According to this theory, if the MCC is not known, it is sufficient to know the elasticity of demand to estimate the price increase that is needed to 'freeze' the increase in demand (Figure 2). The MCC must be considered during the water pricing development process whenever it is practical to do so.

Setting the price level of any public good (like water) under supply capacity constraints is a task scientists have been working on for several years. The decision on the water price level strongly affects and is affected by the decision for system capacity expansion. An important conclusion is that increased peak demand-related price levels can dramatically delay the investments for system capacity expansion, compared to other more inefficient methods of billing. Riley & Scherer (1979) developed such a model where both supply and demand have seasonal sizes and storage capacity is available. Manning & Gallagher (1982) further developed this model to solve two additional problems that were previously ignored: a) the impact of the Inflation Rate to the pricing policies and b) water scarcity-related profits. They used the concept of *arbitrage* (reselling a good at higher prices in the same or another market at different time periods when storage capacity is available). The existence of *arbitrage* has more to do with its time variation than with the stochastic

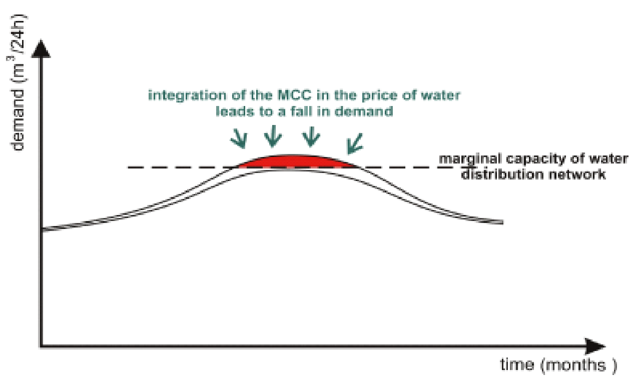

Figure 2 | The fall in demand by incorporating the MCC.

character of the water input volume. The ability to store water becomes more valuable as the demand gets inelastic (Hotelling 1931). The authors believe that this rule, developed to set the optimal value of a good in scarcity supplied in a predefined quantity, is a marginal case of the storage dilemma: the input volume is limited to an initial value during the starting period without storage capacity limits in order to be included in the next time period.

The environmental cost

The environmental cost (EC) expresses the damages due to the waterworks built and the increased water use, caused directly to the environment and indirectly to the users. Today, the EC recovery policies confine themselves to environmental taxes and charges related to freshwater and sewage services included in the water bills. This practice does not offer safe estimates as the role of the politicians in setting the level of those charges is catalytic, leading to an irrational allocation that does not fully recover the EC involved. The basic WFD principle states that the environmental damage is equal to the cost required to restore the environment to its original condition, based on the assumption that the lowest value of an environmental good is equal to the necessary costs for its protection. However, in economic terms, this approach appears inconsistent at first, since it appears to involve both sides of the cost-benefit analysis. It is important to note the disparity: it was argued that the cost of environmental damage is equal to the cost of environmental protection measures, but at least as large as the cost to restore the original environment to good condition. WFD suggests that water bodies should be classified regarding their quality (based on criteria related to ecological and chemical characteristics) in five groups (high, good, moderate, poor and bad). The overall objective is to achieve good quality surface waters by 2015. The cost for a water body to move up in the WFD classification exponentially increases as the ideal situation is approached (Figure 3). On the other hand, as the quality of the water body approaches the 'good status' threshold, economic activities promoted by this quality flourish. These benefits should be integrated into the EC. The EC is a dynamic not a static size. After its full determination and complete recovery through additional charges, the EC will tend to decrease with time. The DC will also decrease, as it is

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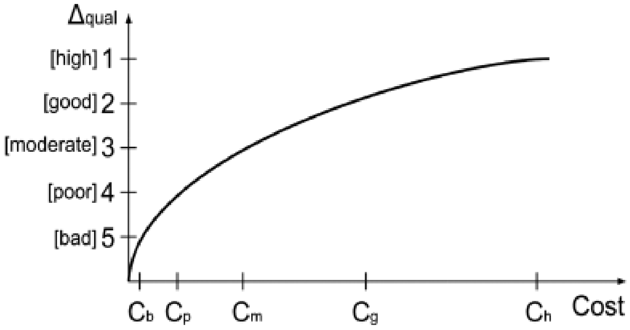

Figure 3 | Water quality improvement costs trend.

directly linked to the EC (this must be considered as an immediate profit). Regarding the discussion on the methods to determine the EC level, the effectiveness of those already applied is strongly questioned. Is it quite safe to determine the magnitude of the EC by utilizing the results of environmental damages analysed from similar cases? Can they offer a guideline based on the proportionality principle? On the other hand, there are researchers proposing that it is possible to transfer financial outputs of environmental damage assessment studies from one area to another. Who is right? Nobody can safely answer this. One thing is for sure: one case does not fit all! For example, in Germany, the EC recovery approach chosen utilized the findings from field studies that took place in pilot regions. There the costs recovered by the environmental taxes imposed were considered to equal the EC involved (Pielen & Interwies 2004). This was a first step to assess the environmental and resource costs. The focus on the current charges/payments data provided by the DG eco 2 (CIS-WG2 B 2004*a*) serves as an evaluation of the portion of the EC already included. There is though a constant worry regarding whether the existing rates can be treated as a reliable database, considering that the levels adopted by the German Länder vary greatly (Görlach & Interwies 2005). This is not due to different quality levels of the environment in these areas. It has more to do with the different tax policies applied. Results showed that the charges do not fully recover the EC. Their recognized added value is that they offer a way to understand how the user reacts to these value levels and accepts them as environmental charges.

Another dispute among the researchers involves the choice of the most representative amount of compensation regarding any environmental impact resulting from the use of water. There are two alternatives: the environmental damage restoration cost (EDRC) and the environmental damage avoidance cost (EDAC). In the authors' opinion, both alternatives can be used to assess the EC depending on when the assessment process takes place. In an ex-ante evaluation, the use of the EDAC is proposed, while in an ex-post or even ongoing evaluation the EDRC is more appropriate. If someone has only one choice, and as a proactively approach is usually less expensive, the use of EDAC seems to be to the benefit of the users.

Also, the cost related to the EC estimation process must be at least balanced by the value of the data obtained (CIS-WG2 B 2004*b*). WFD recommends that a thorough cost-benefit analysis should take place before any field data collection process begins.

Referring once again to the WFD, it states that the determination of the degree of cost recovery should provide information on the extent to which the 'pollutant pays' principle is being satisfied. Supposing that the water services cost (EC included) is fully recovered, a question remaining to be answered has to do with whether this cost is being correctly allocated among the users responsible. A crucial issue not yet addressed involves the allocation and recovery of the EC related to the pollution that agricultural activities are causing to the groundwater resources (considered as the main environmental pressure to water bodies worldwide (WWF 2006)). Even though agriculture is not a direct freshwater user, it is blamed for a huge increase in freshwater services costs due to excessive use of pesticides/fertilizers. These costs must be identified and allocated accordingly. Agricultural-related pollution is characterized by collegiality in terms of participation in the system. In order for agricultural product prices to be kept at rational levels, the State has to motivate farmers to abandon predominantly pollutant farming methods through subsidies. At the same time, a part of the EC results from individual activities (e.g. private wells) where cost recovery should be based on SWOT analysis of each action, in relation to whether or not there are ways to avoid increasing the EC obeying the principle of equal opportunities among the users.

The resource cost

The resource cost (RC) in regions affected by drought equals the lost profits suffered by other users/uses when water

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resources reserves exploitation rate exceeds their supplying capacity (CIS-WG2.6 2002). In many countries of central and northern Europe that are not facing serious water shortage problems, the above definition does not have a solid meaning. Thus, another definition was launched suggesting that the RC occurs when water is not being utilized to its best use, meaning that there are alternative uses available generating higher profits (CIS-WG2.6 2002). According to that definition, the RC expresses the revenue losses caused by the misallocation of water. In countries facing severe water shortage problems, both definitions coexist and the total RC value includes both components (Figure 4).

The authors suggest the cost-benefit cross-checking of water uses/users based on the space-time sustainability analysis among the uses, but also among the same type of users (inter/intra-sustainability). This is compatible with the modern environmental management approaches (sustainable and worth-living). The latter seeks to reduce in time (not just maintain) the cost of equal opportunity among the users and/

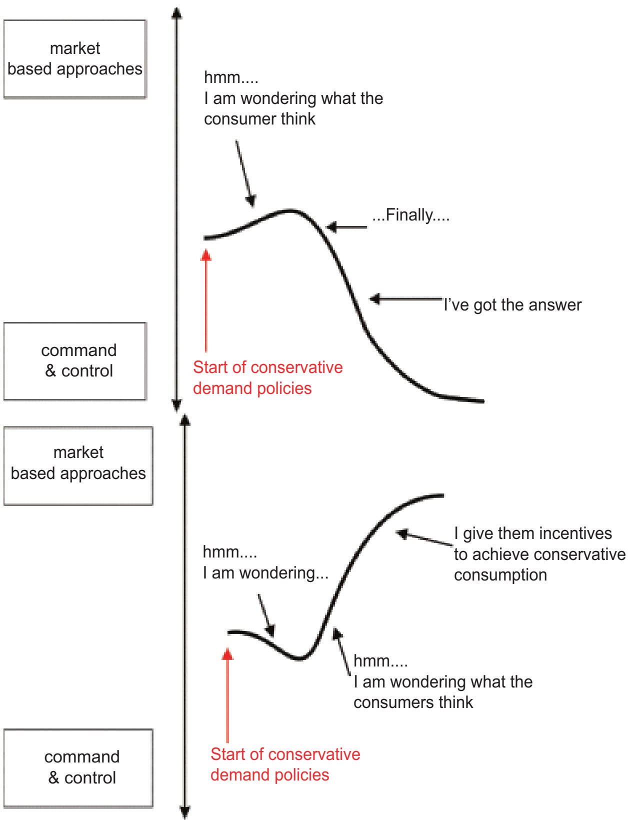

Figure 4 | Conventional (CAC) vs. market-based policies.

or within the same use. Key factors forming the optimal allocation of the water available among the distinct uses based on economic criteria are the local economy characteristics and the sizes of the productive sectors. The final allocation should incorporate social criteria and the strategic interests of the region. In any case, the RC can be defined as the gap between the existing allocation and the optimal one.

The calculation of the RC based on simulation or optimization models provides accurate results (CIS-WG 2B 2004*b*). The optimization models can assess the upper limit of the economic value of the water provided that the system operates in the most cost-effective way. They provide a good understanding of the system operating rules showing how to improve its economic performance. The simulation models assist in determining the economic value of the water considering an a priori formed set of the system's operating functions and water allocation pattern that reflect the priorities/rights of the water use and reproduce the system's current operation. Comparing the results of both approaches, an overview of the RC level can be obtained. The difference between the values of the most cost-effective use of water and the actual water use allocation pattern provides the measure to assess the distance to be covered in order for the current operating scenario to become the optimal one.

Field data collected so far from around the world showed that the water resource opportunity cost gets higher under water scarcity conditions and decreases when water storage is possible. The RC of each water resource changes with time as the resource reserves and supplying capacity are also changing. In the medium to long run the RC tends to decrease following the way the EC changes.

COST ALLOCATION PRINCIPLES

The WFD recommendation to the EU Member States to develop and apply appropriate water pricing policies by 2010, considering (for first time) the RC and the EC related to the use and reuse of water, caused second thoughts regarding the compatibility of the existing water pricing models adopted by the water utilities across the EU. Although the new cost-recovery principle promoting the allocation of the costs to the users based both on their water use level and on the environmental impact set new guidelines, further

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research is necessary, focusing on social/economic/development issues including the continued provision of potable water at affordable prices for the poorest parts of the population. By incorporating the full water cost to its selling price, the water tariff level will dramatically increase, forcing the need for new types of water pricing policies to be developed, in order for the full water cost recovery to actually occur. At the same time, it must be ensured that water continues to be considered a social rather than a commercial good.

Policies to achieve conservative consumption

The conservative demand must be the ultimate goal that should result from market-based policies aimed at individual users (Figure 4). Distinct benefits are expected to appear due to the reduced demand that will go towards achieving the common goal. There are also Conventional (Command and Control – CAC) policies suggested to achieve conservative demand. These policies are small, flexible regulatory approaches that are not performing well. Water use restriction policies should not be an issue for a rational society. Instead, mixed-market policies should be adopted giving incentives to those who comply with the need for a decreased water demand. The build-up of public awareness regarding the water pricing policies and water billing practices is crucial. The water bill should give analytical details not only for the water tariff structure/level, but also for the amount of water used for the daily needs and its cost. This practice is expected to increase the water demand elasticity levels and thus help the effort towards the goal of a conservative demand to be reached.

Theoretical and empirical economic analysis showed that environmental market policies are more cost effective than conventional ones. Market policies encourage water saving through market signals rather than through explicit directives for conservative use. Their well-designed practical tools encourage users to adopt conservative water use practices that are in their interest, and collectively meet policy targets. On the other hand, CAC policies are not flexible enough in achieving the objectives and often drive users to adopt costly water saving practices. The market policies have been proved more effective compared to the CAC ones, for air pollution reduction, both in theory (Crocker 1966; Montgomery 1972) and in practice (Tietenberg 2006; Keohane 2007). Economists worldwide have recently started to study the economic benefits of adopting market policies to achieve conservative water use. The CAC policy for water use reduction is similar to other cases where the restrictions were replaced with tariff policies such as congestion on roads (Parry & Bento 2002). Recent studies show that policies based on increasing the price, instead of imposing water use restrictions, significantly reduce the economic cost of achieving the desirable reduced use (Collinge 1994; Krause *et al.* 2003; Brennan *et al.* 2007).

The water savings derived from market-based policies come as a result of the users' proven ability to decide which water use will reduce according to their needs, mainly due to the increased water price, and not very much due to the restrictions imposed. The understanding of this behaviour is based on those to whom water has a greater value than those who do not respond. How great are the benefits of non-pricing approaches towards effective demand management? Timmins (2003) compared two applied policies, using consumption data from 13 cities in California, USA, where water from drillings was used to cover the water needs. The first policy was based on the mandatory installation of low-flow house devices in toilets. The second included a moderate price increase. The latter proved to be more effective in the long run. The non-pricing water conservation policies suggested to be applied during water shortage periods can be distinguished as the following types: a) mandatory or voluntary adoption of water-saving techniques (house-kit water saving devices); b) water use mandatory restrictions; and c) mixed non-pricing policies (Olmstead *et al.* 2007). Many water utilities worldwide applied type a) policies. The results were contradictory. For example, households using low-flow house devices (e.g. in toilets and showers) tended to use these more (e.g. flushing the toilet twice or extending the time needed for shower) (Mayer *et al.* 1998). Some analysts said that the behaviour resulting in small water savings derived from the fact that the users knew they were part of a survey. Another survey, not facing the similar irregularities, showed that the use of low-flow house devices resulted in significant water saving (20% in the toilet, 9% in the shower). On the contrary, the imposition of water-use restriction policies (e.g. for car-washing, watering the garden) were proved to be inadequate and politically not correct (Mayer *et al.* 1998). A recent water demand survey in California proved that public awareness campaigns followed by motivation policies (subsidies) regarding the replacement of old house water

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devices with new water-saving ones significantly reduced the monthly per capita water consumption. Finally, strict/mandatory water-saving policies were more effective than those based only on voluntary actions and public awareness campaigns (Renwick & Green 2000).

SUGGESTIONS AND APPROACHES

Ways to avoid social injustice: rational allocation of costs

Effective water pricing policies promote efficient (conservative) water use. The demand for goods and services is greatly based on their values. In the long run, prices affect demand models, which in turn affect the supply process and subsequently the costs. Although the selling price of a good is not the only factor determining its demand level, it plays a crucial role. When the service costs of a good are proportionally allocated to the users, pricing is more efficient and socially just. The political definition of the sense of justice integrates the following fundamental principles: fairness, impartiality and accessibility (e.g. water). As water is an absolutely necessary ingredient of life, everyone should be able to have access to a reliable, economically affordable source of fresh, good quality water. The affordability criteria do not undermine either the effectiveness or the sustainability of the full cost recovery criteria. Although efficiency is necessary, it is not a sufficient criterion of sustainability (Klawitter 2003). The concept of sustainability raises the issue of subsidies, these often being the only possibility for poor urban and rural users to have access to water. The parties involved in payment of the water services are households, industry (tourism included), agriculture, water companies and the State. Each has its own needs and sensitivities surrounding the issue of proper pricing. The domestic users, however, form the most vulnerable group. Since the water price, integrating the concept of its full cost recovery, will dramatically increase, developing a new type of pricing and billing to ensure that this cost will actually be collected is necessary. The structure/level of the water tariffs should be socially fair (from the poorer to the wealthier population groups). Water pricing based on the water volume consumed allows discrimination to take place if the consumed quantities vary significantly. Different kinds of users and uses create different types of cost. In an effective pricing policy, a large portion of the cost to be recovered should be paid by the larger users, those responsible for the costs related to the demand peaks, considering seasonal use and other indicators that may exist. Water pricing as a conservative-use promoting tool has limitations (e.g. for households with low income, the amount of water actually used is less responsive to price changes as it reaches the threshold volume necessary to live life with dignity). Although increased water prices can be an effective message, at the same time they can cause suffocation of users, increasing social disparities if the water quantities actually consumed are limited.

The role of the State is multi-layered and crucial. The State should support the lower income and other vulnerable population groups by providing grants/subsidies for a certain minimum amount of per capita consumption (dignity threshold), especially for socially vulnerable groups who consume large quantities of water (large families). Then, an upper limit of per capita use must be defined, the excess of which would be considered a luxury and invoiced accordingly. Subsidies should be given to all households to motivate them to replace the old water-consuming devices with new water-saving ones. The authors suggest water utilities should also cover a part of this cost, as they will in the long run enjoy the benefits of the resulting water conservation, by postponing new investments during their quest for new water reserves. Grants/subsidies may be considered as internal payments among the users and uses of the water system and as external directly to the water utilities. The latter can act as a deficiency payment from the State or assistance to the consumers by government or NGOs. The most common subsidies among the different users/uses include payments by the wealthier to the poorer users. Their main goal is to ensure that even the poorest population groups will have access to a minimum per capita water use (dignity threshold), considering that: a) an average person needs at least 50 litres/day (5 litres drinking, 10 litres cooking, 15 litres washing and 20 litres for drainage) (Gleick 2000); and b) water-use related expenses should not exceed 2% of family income (AWWA 2000).

The authors also suggest the State should establish a detailed process that will provide each household with a Water Saving Efficiency Certificate according to its water saving capacity level. Something similar applies to the energy performance certificate (Directive 2002/91/EC) given to a

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property after thorough inspection, indicating its energy efficiency level. Distinct levels (A, B, C) have been established. In the shorter run, the whole process, also supported by a targeted public awareness process, will result in decreased real estate value prices for low-efficiency properties. This will inevitably force owners to take actions to upgrade the efficiency level of their property. The ultimate goal (reduced energy use) will then be achieved. The same principle can also be applied for water-saving efficiency. Similar outcomes are expected. The certification should also be extended to connection pipes located within the property limits. This will eventually reduce the water losses occurring in pipes where the water utilities do not have authorization to take action.

The role of water utilities is also decisive. Direct knowledge of the water-use level and daily/seasonal fluctuations, along with the experience of what causes late payments or even debts to the users, is a useful tool for rational water pricing and to define the population groups that will need to be supported through subsidies. Due to the increased cost of water, water utilities must reconsider their attitude towards the water losses (leaks/breaks), since neglect of these will prove costly.

Industries, apart from applying market-based water-saving policies, must fully pay for the part of the EC they are causing, in the same way as they are forced to do for the air pollution they are causing. State mechanisms should be alert in order that this cost is not 'reclaimed' by the customers buying industrial products. The water tariffs must include water-related environmental taxes, whose level should depend on the compliance rate of the industry towards conservative water management.

Regarding the part of the full cost of urban water that must be paid by farmers, although they do not directly 'interfere' with the urban water supply process, their activities usually result in a significant increase of the EC and the RC of the available water resources, through the overuse of pesticides/fertilizers (EC) and uncontrolled drilling (RC). In the case of the agricultural sector being forced to pay its part of the full cost of urban water, this is expected to be 'reclaimed' by customers buying farmers' products. Thus, State mechanisms should be alert to prevent this expectation from occurring. Additionally, the State must at least support the smaller farmers. The result of adopting new water pricing models will force the state to establish a more rational method regarding the crop types it promotes. By applying the new pricing, water-need crops will be either displaced from countries facing water shortage problems, or will become less profitable. The State using a motivation policy should aid farmers in changing their crops and irrigation systems.

Allocation of the water losses-related cost

Regarding the water losses occurring in a pipe network due to leaks/breaks, the following must be noted. Water losses must be treated as an alternative water use causing expenses (intake/supply/treatment) instead of generating profits. The Current Annual Real Losses (CARL) represent the existing water losses, while the Unavoidable Annual Real Losses (UARL) equal the minimum CARL level that can be achieved, utilizing appropriate strategies (Figure 5). In any network, the UARL level in litres/day can be assessed using the empirical expression (1), where P is the average operating pressure (m), Lm is the mains total length (km), Nc is the number of service connections and Lp is their total length (km) (up to the user's meter) (Lambert *et al.* 1999):

$$\mathrm{UARL} = (18 \times \mathrm{Lm} + 0.80 \times \mathrm{Nc} + 25 \times \mathrm{Lp}) \times \mathrm{P} \qquad (1)$$

The Economic Annual Real Losses (EARL) represent the CARL level that it would be cost-effective to reach. The EARL form a threshold (CARL down limit) resulting from a

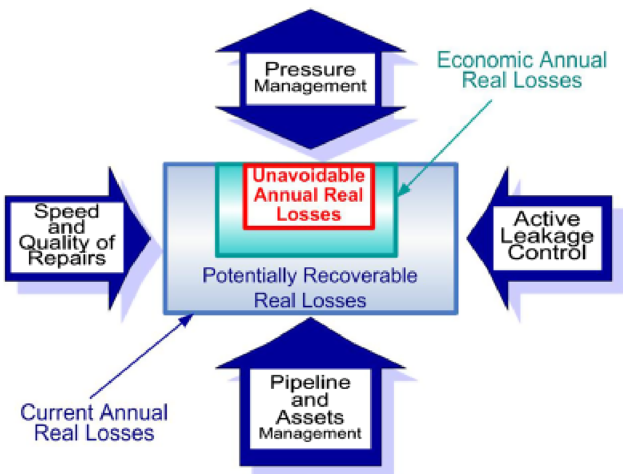

Figure 5 | Ways to reduce water losses.

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cost-benefit analysis, as the cost to further reduce water losses exceeds the expected benefits. Finally, when the unit water value increases, EARL, UARL and their difference tend to decrease (Figure 6).

The water utility is responsible for the largest part of the water losses occurring in the network. Considering the increased value of the water (after its full cost recovery), every water utility must reconsider its attitude towards these losses, which will be costly if neglected. Based on the principles set by the WFD (full cost recovery; pollutant pays; proportionality), the following full water cost (FWC) allocation is proposed:

- The consumers must pay the FWC of the water losses (apparent) occurring within their property.
- Regarding the FWC of the UARL, consumers should pay the FWC of a minimum accepted water losses level (5% of the System Input Volume), in return for having access to water.
- The FWC of the remaining part of the UARL should be paid by both the customers and the water utility, according to the water volume each one uses. The same should be the case regarding the FWC of the difference EARL – UARL.
- The water utility must pay the FWC of the difference CARL – EARL, as a penalty for the network's poor operating performance level.
- The State should pay its part of the above costs (in the form of grants to the water utilities) if involved in the construction and initial management of the network infrastructure. The size of the State's contribution should be discussed (negotiated) with the water utility.

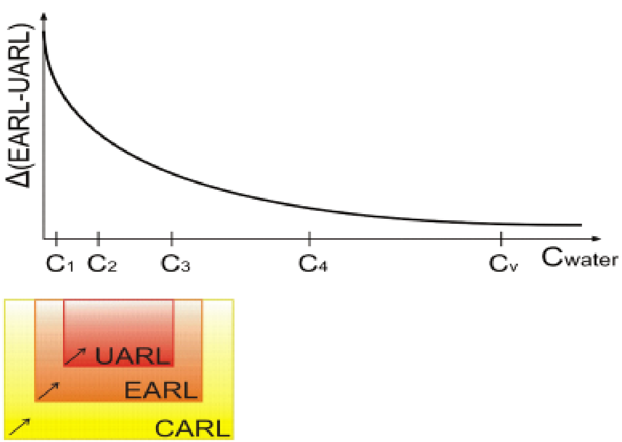

Figure 6 | Moving from EARL to UARL (cost).

Regarding the investment costs necessary to reduce the CARL level to the EARL one (resulting in reduced DC, EC, RC due to the reduced water demand achieved) the following allocation is proposed:

- The water utility must directly pay the biggest part of these costs instead of asking its customers to do so, through specific charges included in the water tariffs (expansion charges).
- The customers should cover only a part of these costs, as they will enjoy the benefits of reduced water prices, due to the reduced EC and RC resulting from the reduced water demand level due to the minimized water losses.
- Finally, the State should pay its part (in the form of grants to the water utilities) if involved in the construction and initial management of the network infrastructure. The size of the State's contribution should be discussed (negotiated) with the water utility.

The methodological framework proposed to asses the FWC

To calculate the full cost of water supply, several factors related to the water resource, water users and those responsible for pollution must be taken into account (Figure 7). This cost changes with time. Its components affect one another while also being affected by other common factors. The first point has to do with the necessity to calculate the FWC, taking into account the spatial and time variation of its components, as they depend on the spatial and temporal variation of the characteristics of the users (size, income, water-use pattern, seasonal change), of the water resources (spatial and time variation of supplying capacity; hydraulic cooperation; pollution) and the figures of the economy defining the price adjustment factors to avoid economic obsolescence. Thus, the calculation of the FWC should refer to a specific area size (river basin) and time period (following the hydrological models and scenarios regarding the change of economic indicators). Calculations should be made for each type of use (domestic; municipal/public; social; water losses; industrial), checking the sensitivity of the model towards its parameters. The calculation should include the Damage/Risk Avoidance Cost at a technical and economic level.

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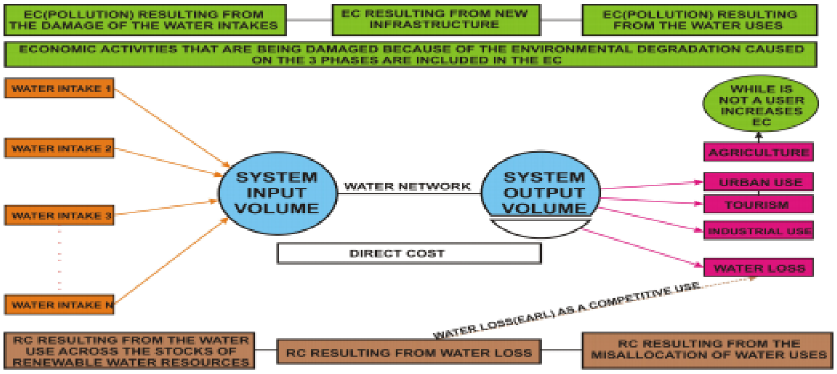

Figure 7 | Overview of the FWC assessment process.

Considering the above, several models must work together to calculate the FWC components. These models should forecast the space-time variation of specific parameters, such as:

- the water resources reserves level by using various sub-models (e.g. a hydrological model to assess the inflow to the resource; a ground or surface water hydrology model to assess what the water resource can offer; a water-intake works operation model). The resulting scenarios will form the 'water offering matrix', which along with the spatial and time variation of the water treatment plants capacity and of the water supply network carrying capacity will form the 'water supply matrix'. For each part of this system the results of a sensitivity, reliability and availability analysis will be also taken into consideration. The water quality characteristics of each water resource can be also included in the 'water supply matrix' (Figure 8).
- The water demand pattern for each type of use/user, considering the factors affecting the level of demand (e.g. income, price, race, religion, size of property), along with external factors (e.g. climate, network operation and maintenance practices, water losses levels). The results will form the 'water demand matrix'. For each part of this system the results of a sensitivity, reliability and availability analysis will be also taken into consideration (Figure 8).
- The figures of the economy that define the water price adjustment factors to avoid economic obsolescence, and the profit levels of the alternative (competing) water uses (revenue losses). The results form the 'water finance matrix' (Figure 8).

The final outcome, currently being developed by the authors, will form an Expert Decision Support System (Figure 8), where data input will take place in a monthly step, to record any time variations. Regarding the water losses, as the price of the water is expected to increase obeying a FWC

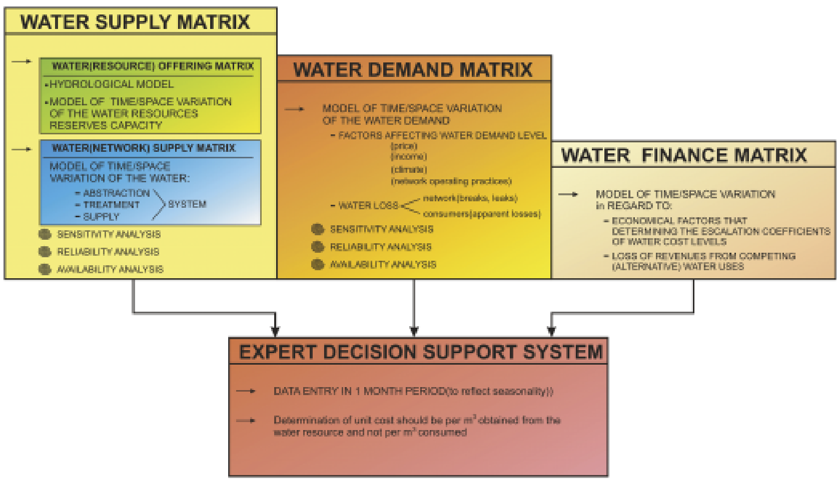

Figure 8 | Components of a suggested Expert Decision Support System.

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recovery policy, the EARL threshold will tend to decrease approaching the UARL level (the costs of the measures to reduce the water losses level will tend to be more cost-effective). Additionally, by reducing the water losses level, the related DC and RC will also decrease, as less water will need to outflow from the water resource to cover the water demands. The same may result with the EC level, in case the quality of the water in a water resource depends on its reserves. As the levels of the FWC components will decrease, the water price will drop. This may affect the water-use level (depending on the water price elasticity index). If it does, the increased water demand will result in increased water prices, forcing water use to decrease. It is expected that in the long run the entire system will balance to an almost-constant unit price of water, or a smooth increase trend following the increased demand.

There is another point that should also be noted regarding the impacts the water losses reduction strategies based on pressure management techniques have on the UARL/NRW levels. As mentioned, the UARL level can be calculated from (1). This level directly depends on the mean operating pressure of the network. As this pressure drops, the UARL level will follow, decreasing the NRW level. This means that less water needs to be taken from the water resources to meet the water demands. The steps of an action plan regarding the implementation of a water losses reduction strategy based on pressure management are as follows (applicable also for any water losses reduction strategy adopted):

1. Assess the system's supplying capacity (water resources reserves level; capacity of the water intake works; carrying capacity of the water aqueducts).
2. Monitor the entire system (water resources; water supply/distribution network; water storage tanks) e.g. with a SCADA.
3. Develop a simulation model for the entire system (use the data from the SCADA to calibrate and validate it).
4. Estimate the UARL levels based on the current operating pressure of the water distribution network using the empirical Equation (1).
5. Form the Water Balance of the water distribution network and assess the NRW levels.
6. Estimate the DC, EC and RC levels based on the current total water demand (ex-ante evaluation process). Calculate the FWC level.
7. Determine the new (higher) water price levels based on the current FWC levels (ex-ante evaluation process). These higher water price levels will result in a reduced total actual water consumption due to the water-price oriented elasticity of demand (as the price gets higher, the demand decreases).
8. Determine the new (lower) water demand level and the new (lower) EARL level based on the new (higher) water prices set (ex-ante evaluation process).
9. Pinpoint the crucial network points for pressure management (e.g. zoning through PRVs) or even for DMAs formation. Apply the most cost-effective water losses strategy (based on a thorough cost-benefit analysis).
10. Estimate the new (lower) UARL, NRW levels based on the reduced operating pressure of the network.
11. Estimate the new (lower) DC, EC and RC levels due to the reduced water demand (ex-post evaluation process). Calculate the new (lower) FWC level.
12. Determine the new (lower) water price levels based on the new (lower) FWC levels. These lower water price levels will "force" the total actual water consumption to increase due to the water-price oriented elasticity of demand.
13. Determine the new water demand and EARL levels based on the new water prices set.
14. Repeat steps 9–13. The system will eventually balance to its 'sustainability level'. The whole process should be repeated based on the predefined water price level adjustment period (e.g. every 2–3 years).

CONCLUSIONS

The three sub-costs (direct – DC; environmental – EC; resource – RC) forming the full water cost (FWC) affect one another (e.g. reduction of EC means better water quality, resulting in reduced DC due to less treatment necessary in the water treatment plants). These sub-costs are of dynamic sizes, as they depend on various parameters (e.g. time season, geographic region, population density, economic activity). The above interconnection makes the precise definition of which factor is responsible, and to what extent, for full water cost recovery a very intriguing task to achieve.

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The calculation of the DC, although it seems easy, requires special attention, as it depends on many factors varying in space and time. Additionally, the DC includes sub-costs affected by the network management practices. A typical example is the time and space variation of the repair and replacement costs of network pipe, and the rate of failures occurrence. In order for the DC to be safely accessed a hierarchical analysis of the troubleshooting network parts is needed using specified models along with models determining the optimal pipe replacement time (Kanakoudis 2004; Kanakoudis & Tolikas 2001). Whenever pipe replacement and preventive maintenance works take place on time, the operation and maintenance costs of the network are significantly reduced.

Crucial in estimating the levels of FWC components is the determination of the water demand level, and its spatial and time variation. It should be noted that the determination of the unit water costs (per m^3) should refer to the water volume supplied by the resource, and not to what was finally consumed. As the level of these costs depends on the size of the total water demand, including water losses occurring in the network and within the property of the consumer (usually not accounted for as they lie below the water meter threshold), during the successive adjustments of the water costs levels, any demand restrictions due to network operation/maintenance practices changes and differentiations of water-use habits by the customers should be taken into account. This will ensure a more accurate assessment of the cost of water along with its socially just allocation.

The water losses occurring in the pipe network, along with those occurring within the limits of the customer's property, should be handled the same way, as they both represent water volume not actually being used (a false water use). Additionally, as, they are not being charged for, they do not produce revenues for the water utility (both volumes are parts of the Non Revenue Water Index). In order for this NRW to be minimized, the following approach is being suggested by the authors. As the FWC level depends on the size of the total water demand, its sub-costs should be calculated for two different demand levels that will differ by the amount of the water losses. The resulting difference in the FWR level should be proportionately charged to the users responsible for these water losses.

To distribute the cost of the water losses occurring in a water supply network that carries the water from alternative water resources, the *Micro-flow Distribution & Complete Mixing Assumption Method* was applied (Wood & Ormsbee 1989; Jowitt & Xu 1993). Additionally, the water losses cost should also include the cost to eventually 'replace' those volumes from the next cheapest water resource available considering also any extra costs related to using alternative water supply paths (available due to the structure of the water supply network).

Finally, the whole FWC recovery process should refer to a specific space area. Following the guidelines set by the WFD, this process should take place within the limits of a River Basin District. The problem is simple. The information available regarding the water-related costs and revenues collected refer to areas usually not lying within the boundaries of only one River Basin District (where more than one water utility operates). To evaluate both the EC and the RC related to a water resource, it is important to determine the area where the environmental impact takes place (WWF 2006). Thus, the contribution of each water utility as a percentage of environmental damage and depletion of natural reserves of the whole River Basin District should be calculated.

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