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REUSE IN THE GLOBAL WATER CYCLE: AN APPROACH TO THE CONCEPT OF THE PRODUCT LIFE CYCLE APPLIED TO WATER

SUMMARY

The quality of reclaimed water is the result of a chain of decisions and actions beginning at the moment of extracting first use natural resources and continuing throughout the whole water cycle right up to the last reuse operations. If the water use cycle is planned on a global scale from its beginnings with a view to facilitating reuse at the end of the cycle, it will be possible to control the deterioration processes of the water so that its reuse is possible with limited costs and without loss of resources. If, on the other hand, decisions are taken at each stage of the water cycle without taking into account the effects that these may have on the potential for future reuse, this will result in the need for costly post-treatments, the loss of resources and possibly even in reuse operations becoming economically non-viable. This paper contains some reflections on these aspects throughout the successive stages of the water cycle, accompanied by some examples taken from cities or systems on the Spanish Mediterranean coast.

Key words: reuse, salinity, conductivity, water resource management, life cycle

INTRODUCTION

The New Water Culture (NWC) advocates management of the water cycle which is capable of satisfying the needs of the population (urban, industrial, agricultural) without harming aquatic ecosystems. The main objective of the NWC is the improvement in the quality and the state of conservation of aquatic ecosystems, based on the conviction that not only will these improvements result in environmental benefits, but they will also translate into improved quality of drinking water and a greater guarantee of the water supply.

The New Water Culture is based on a clearly ecological conceptual foundation. The ecosystemic vision of the physical world views natural phenomena as cyclical flux of materials and energy which in nature are usually closed by processes of recycling matter and by the provision of external energy to each natural system. When these cycles are left open or are changed due to human intervention, environmental deterioration ensues. This is seen in various forms of pollution, exhaustion of resources or other situations of unsustainability.

This ecosystemic focus is entirely applicable to water cycles. Any body of water, whether continental or marine, surface or underground, is situated at a particular point in the natural water cycle, and at this point will be potentially capable of providing social, environmental or economic usefulness and of sustaining specific aquatic ecosystems. The actions or pressure exerted on this body of water can have an influence on other stages of the cycle, modifying the economic or ecological potential of these stages.

From this perspective, wastewater cannot be considered and treated as waste that appears at the end of a linear process of water use and that may be suitable for reuse. Wastewater forms an integral part of the water cycle, with no conceptual differences between it and water from any of the earlier stages. In this sense wastewater merits the qualification of a resource, rather than as waste, in the same way that any other body of water at any stage of the cycle can be considered a resource with specific potential for economic and ecological utility.

As a result, so that waste water or reclaimable resources are capable of offering the best possible hydrological or environmental benefits, the anticipated subsequent uses for the water should be taken into consideration in the design of any stage in the water use cycle, including the potential use of reclaimable water. To obtain maximum utility from the latter, measures should be adopted throughout the cycle that ensure that at the end of the cycle a reclaimed resource is obtained that is fully suitable for the uses anticipated, at the lowest possible cost.

To attain this objective, it is necessary to overcome the idea that the reclamation and later reuse of water begin in the wastewater treatment plant. In reality, the reuse of water begins long before that, from the moment of extraction of the natural resource which, after storage, transportation, conditioning, use and collection following its first use, will result in the reclaimable resource. With this approach, the design and management of the final stages of treatment and reuse will depend to a large extent on the decisions that have been adopted throughout the entire cycle, and therefore the optimisation of the system of reuse should be carried out for the cycle as a whole, from a global perspective.

This leads to the so-called “from mine to dump” or “product life cycle” approaches, applied in this case to the water cycle. In analyses of this type, which have been common for some years in industry, the demands of the recycling or reuse of the product are taken into account from the design phase of the product to the end of its useful life, spanning all the stages of marketing, use and disposal of the product.

This paper is intended to offer a general vision of the implications that a life cycle approach may have on the management of the different phases making up the water cycle.

MANAGEMENT OF THE WATER CYCLE FROM THE PERSPECTIVE OF REUSE

As indicated in the section above, in order for reclaimable resources to fulfil appropriately the functions that may be required of them, and for this to be the case with the minimum economic and environmental costs, it is necessary for water to be given suitable treatment throughout its cycle of use, from the collection and conditioning of water from the natural environment, through the use of the water that is generated later by the reclaimable resource flows and including the processes of treatment, transportation and application of the reclaimed water.

The full water cycle can be broken down into a series of phases, for each one of which it is possible to formulate specific considerations or recommendations that may be favourable at a specific point to the conditions of water reuse. In this case the analysis will focus on the urban water cycle with subsequent reuse. There are other possible schemata for reuse or for combined uses of water in which urban water use is not involved which will not be covered by this paper, but that are of interest nonetheless. For example, specific agricultural waters may have environmental uses through their returns or vice versa, certain water flows intended for environmental uses may later be destined for other uses. In all of these cases it can be considered that there is reuse of water and that it may be necessary to apply specific measures throughout the water cycle to facilitate or to optimise this reuse.

It is also interesting to bear in mind the well-known differentiation between the recycling and reuse of water. Reuse is defined as the use of water that was originally used for a specific application for a different application, while recycling is defined as the use of water in the same application for which it was originally used. The recycling of water is very common in different industrial sectors and there are also applications for it in residential activities (grey water), in ornamental installations and for many other purposes. Without denying in this case its potential for the optimising of the water cycle, this paper will not deal with the recycling of water, but rather solely with its reuse.

Focusing on the urban water cycle with the final perspective of reuse, the global cycle to be considered can be broken down into the following phases:

1. Upstream catchment
2. The use of the water
3. The collection of reclaimable water
4. Reclamation treatment

A common reference point throughout the cycle with a view to the reuse of water is the optimising of the quality / cost relationship of the reclaimed water obtained and its appropriateness for the desired purpose in terms both of quality standards and the adaptation of its cost to the capacity to pay of the users for whom it is intended. Any important discrepancy in this sense may represent the failure of a reuse project.

Both the quality and the cost are defined in terms of a number of parameters or dimensions: for quality, there are dozens of physicochemical indicators of the usefulness of water for different uses. The cost, for its part, is a multi-dimensional value as it incorporates economic, ecological and social costs, not all of which can be reduced to monetary values. This multidimensional character confers a distinct complexity on the global management of the water cycle, which may become impossible to overcome if the problems are not simplified by focusing analyses on a limited series of indicators.

This paper will approach aspects related to various facets of water quality and to different dimensions of costs. However, the examples with which the progress thorough the water cycle shall be illustrated will be based on one single quality parameter (the salinity of the water) and on one single dimension of the cost (the economic cost of hydrological services) to make an approachable analysis and to illustrate more clearly the analyses and suggestions collected together in the text. Wherever possible, these examples will refer to one specific situation, that of Alicante and its neighbouring regions, where in recent years interesting experience – both positive and negative – has been gained in matters of water reuse.

UPSTREAM CATCHMENT

At first glance it would seem that the upstream catchment of natural first-use water to meet urban supply needs bears little relation to reuse policies that may be applied at the end of the cycle. Nevertheless, in practice the qualities of water at the start of the cycle can have a considerable influence on the possibilities for reuse, especially in terms of salinity, which is a determining parameter for the suitability of the water for some of the most habitual uses in water reuse, such as agricultural irrigation, urban or leisure uses.

Salinity is a conservative parameter, which means that it is not affected by the natural processes of self-purifying of water and in principle it can only be modified by dilution. For this reason, the salinity of the water entering an urban system constitutes a base level onto which the successive increases in salinity resulting from every use or handling operation of the water are added throughout the water cycle.

It is therefore important not only to improve the quality of the water supply in itself, but also with a view to its subsequent reuse, to ensure that the water first entering a water supply has the lowest possible level of salinity.

Although in many cases there are few options to choose between different sources of the supply, in some cases there are different options of action that can result in considerable improvements to water salinity. Nonetheless, in those cases where there is a choice between more than one source, or between combinations of sources, which can provide water of different levels of salinity, in general the most economical collection or the collection offering the greatest guarantee is chosen, disregarding continuous or temporary supplies of water of a higher quality that are more costly, or that present technical difficulties.

The case of the Tagus-Segura aqueduct (TSA) is an example of this type of situation. Since this water transfer system was brought into use in 1980, much of the water supply for the provinces of Murcia and Alicante have come from the Tagus-Segura water transfer. The origin of this water is the system of reservoirs of Entrepeñas and Buendía, situated in the headwaters of the river Tagus in Guadalajara. The waters from these two macro reservoirs mix in the Bolarque reservoir and from there they are transferred to the Tagus-Segura aqueduct. However, the quality of the water of Entrepeñas, with a conductivity level of around 400 µS/cm, is significantly better than that of Buendía, which reaches up to 900 µS/cm, with a high presence of sulphates (Gascó, J.M. et al, 2004). Entrepeñas supplies an average of some 400 hm^3 annually, while Buendía supplies some 600 hm^3.

The mixing of the waters in their conveyance means that the salinity of the water sent to the Mediterranean coast, an area with generalised salinity problems, is of some 700 µS/cm at source. This is not a high level of conductivity, but it is clearly higher than the level that would be obtained by reducing the volume of the transfer, sending via the aqueduct water solely or mainly from Entrepeñas, and avoiding its mixing with the Júcar by means of the by-pass requested by Valencian irrigators at the Alarcón reservoir. For transfer volumes similar to current levels, the possibility of operating in time divisions should have been researched, so that in some months higher quality water would be sent for water supplies, and throughout the rest of the year, lower-quality water intended for use in irrigation would be sent. This would have implied a separation of the waters at their destination, with the reservoirs in the upper waters of the Segura specialising in high quality water (Cenajo) and standard quality water (Talave). In general, it is almost always possible to find a solution that avoids the unwanted mixing of waters of different qualities.

However, it should be noted that as the Tagus also has salinity problems (conductivity in Toledo is greater than 1,500 µS/cm, due to discharge from Madrid), the rerouting of all the good quality water along the TSA could significantly worsen the quality of the middle Tagus. This means that good quality water could possibly only be transferred for the supply fraction of the TSA, which would cause additional complications for the separation of qualities throughout the system. In the lower stretches, the quality of the water of the Tagus would improve to a certain extent, as it receives significant runoff water from the Central System, with low levels of salts. For example, the average salinity of the river Tiétar is 105 µS/cm.

In any case, by ignoring the question of water quality in the design of the TSA, potential problems were generated that are now becoming clear. When the water descends from Bolarque charged with sulphates at the limit of potability (246 mg/l) (MoE, 2000) and mixes with the water of the Júcar at Alarcón, with concentrations of sulphates that are the same as or greater than these, the water leaving the reservoir can contain up to 450 mg/l of sulphates (Paredes, J., 2004). These sulphates have caused problems in the water supply for Albacete, which have led to the need to construct a reverse osmosis plant at a cost of over 12 million Euros, which will begin operating in 2006, with the consequent rise in cost of the water and the difficulties that will arise for the disposal of the brine in an inland area. It is of interest to remember that supplying Albacete with water from the Júcar was suggested when extensive agriculture began to cause the deterioration of the water in the aquifer of eastern La Mancha, which until then had been the exclusive source of the city's water supply.

Had attention been paid to the quality of water in the TSA, the water reaching the Segura Basin would have had significantly lower conductivity than it has at present. If the later mixing of this water with other water with high conductivity in the Segura basin had been avoided, the quality of the water supply in the Taibilla river system would have noticeably increased, and the improvement would have also affected the reused water which, in the Segura basin and in the regions of Alicante supplied with water from the Taibilla, is a very high percentage of the water used.

Although at present measures are being considered to reduce the effects of these mixtures, such as the Talave-Cenajo connection, it is very difficult to solve the problem entirely. The improvements in quality, both for Alicante and other cities on the Spanish Mediterranean coast, will come from the desalination of seawater.

The use of desalinated water has distinct advantages in the salinity cycle in Mediterranean cities and can be a good means of support to facilitate agricultural reuse of waste water in these cities. Normally for urban supply uses and starting from seawater, desalinated water is supplied with salinity levels of between 250 and 400 mg/l, that is, a conductivity level of between 400 and 600 µS/cm. This range of salinity is far lower than almost all of the natural water resources available on the Mediterranean coast, which means that the use of desalinated water in these areas means a distinct improvement in the average quality of water at the start of the cycle, in terms of both conductivity and other parameters.

In Alicante, the water arriving from the Taibilla Canals is of a quality affected by the successive mixing of waters in the TSA, first in Bolarque, then in the Júcar, then in the river Mundo and following that in the Segura. On exit from the Torrealta water treatment plant, the average conductivity of the water is over 1,000 µS/cm (MoE, 2002). If the water in the Tagus-Segura water transfer system intended for supply purposes did not go through the mixing mentioned above, or at least not in all of them, the quality of water on entry to Alicante could be significantly better than it is at present. However, the mixing of the waters of the Taibilla with high quality underground water from the Alto Vinalopó has so far enabled the distribution in the region’s capital of water of a level of around 800 µS/cm, which is a very acceptable quality. However, the progressive exhaustion of the wells of Alto Vinalopó means that this solution cannot be continued into the future.

The alternative for Alicante, and for the group of coastal regions of this province, is the desalination of seawater. In the last two years, the coming into operation of the desalination plant in Alicante, which produces water of under 500 µS/cm, has enabled a reduction in the average salinity of the water distributed in the city, although at present there is no detailed information available concerning the global average value obtained, which also varies between the different zones of the city.

THE USE OF WATER

The increase in salinity of water as it passes through a cycle of urban use, in the absence of significant industrial activities, leads to a jump in salinity of between 600 and 1,000 µS/cm, although this is a reference range with a wide margin for variation depending on very diverse factors.

Probably the most important determining factor in the increase in conductivity in the urban use of water is the quality of the water on entry. The introduction of poor quality water into an urban cycle generates a vicious circle of rectification operations and specific forms of use of the water which result in even greater deterioration, which could be avoided if the quality of the water on entry were better.

Firstly, the low quality of the water is usually indicative of scarcity of resources and is usually accompanied by high treatment costs and, in general, high water prices. The highest water prices stimulate hydrological efficiency, which is clearly positive from a quantitative point of view and from the point of view of pressure on natural resources, but this has its counterbalance in higher levels of deterioration of the water in the urban use cycle. If water has to cover the same hydrological services (washing, hygiene etc.) with a lower volume of the resource available, the final deterioration level will be greater.

Furthermore, for certain uses water with high levels of salinity requires decalcification or other rectification procedures that incorporate new salt loads. Moreover, low quality water usually requires higher doses of soap and detergent.

In Mediterranean cities, the good climatic conditions and the strong sunshine favour evaporation and the consequent saline concentration of the water in swimming pools and other outdoor uses, such as ornamental fountains, hoses, etc. The infrequent replacement of water in swimming pools, in many cases at intervals of over one year, even in public establishments in which the swimming pool is used intensively, not only increases salinity by evaporation, but also requires the use of large quantities of chemical additives to maintain the water, which in turn generate further increases in salinity.

In applications that are industrial or commercial in nature, such as refrigeration, but also in numerous industrial washing activities, increases in water prices mean that applications in closed circuits are becoming more widespread, along with local water recycling systems in which only losses due to evaporation or saturation with solutes are replaced. When this water is periodically discarded, it tends to have high salt loads.

Undoubtedly all of these actions are positive in themselves from the point of view of water resource conservation, and no doubt some of them should be encouraged. However, the reality is that the increase in salinity of wastewater flows is the other side of the coin of the saving and efficient use of water, and can be extremely problematic when these practices are used on domestic water with high salinity levels.

In Alicante, the average conductivity of the water that reaches the WWTPs is, at best, triple that of the water first entering the cycle. The water reaching such high levels is due to a great extent to the high levels of efficiency characteristic of the water supply system (>85% performance) and to the patterns of water use in the city, with the decalcification plants, swimming pools and other uses generating highly saline water also playing a part in the process (Estevan, A. and Ballesteros, G., 1996). Nevertheless, to this level of salinity due to the water cycle, specific situations which occur in the drainage system are added. These will be analysed in the next section.

THE COLLECTION OF RECLAIMABLE WATER

Wastewater and reclaimable water are a resource that should be looked after and protected in order to avoid additional deterioration which would make its later reuse more difficult or more expensive. The coherent application of this principle implies, in many cases, the need to rethink drainage systems down to their most basic aspects.

With a perspective firmly based on drainage, which is the way collector networks are usually designed, the purpose of these networks is to carry wastewater to treatment plants in the most economical way possible, avoiding leaks that could contaminate aquifers or generate other types of sanitary problems.

From the point of view of reuse, the drainage networks should be designed with the aim of protecting the reclaimable resource and avoiding additional deterioration which could make subsequent reuse more difficult. Some criteria to be applied to this end are:

- As a general rule, effluent from industrial estates should not be mixed with urban-residential effluent.
- Industrial discharge of wastewater with high salinity should not be authorised.
- Small-scale desalination operations (in hotels, public centres etc.) from which the brine is discharged directly into the drainage system should not be authorised. Illegal desalination should be penalised.
- Where possible, separating drainage systems should be installed for the separation of rainwater and wastewater.
- Sewage pipe networks should be well maintained.
- Intrusion from phreatic or salt water into the drainage system (in the coastal sections) should be avoided.
- Storm basins should be installed to separate rainwater from runoff water from streets and roads.

If these and other possible precautions are not taken to reduce as far as possible the salinity of wastewater, this wastewater could reach levels of salinity that would cause extreme difficulties for its reuse.

The mixture of wastewaters from different sources to be treated in a unified plant can cause serious deterioration in the collective reclaimable water resources. A case of this type of situation that has been studied in depth is the city of Ontinyent, one of the main centres of the textiles industry in the Autonomous Community of Valencia (Estevan, A., 2003). The WWTP of Ontinyent receives its input from two sources, which are then joined inside the plant:

- The first source collects waste water from the centre of Ontinyent, together with waste water from the “Sant Vicent” industrial estate, from some industries located in the urban centre or the surrounding are, and from the scattered houses that are connected to the sewage system.

- The second collects wastewater from the “El Plá" industrial estate, along with the wastewater, both urban and industrial, from Agullent.

These wastewaters are mixed on entry into the plant and are then homogenised and neutralised before the process, which consists of a secondary treatment with activated sludge, begins.

The salinity of the waste water from the urban centre of Ontinyent is slightly under 1,000 µS/cm, a reasonable figure, but which is to be expected, bearing in mind the fact that the conductivity of the water on entering the cycle is very low (around 400 µS/cm) and that the urban-residential use cycle of the water in this city increases conductivity by little over 500 µS/cm, particularly as decalcifiers are scarcely used due to the high quality of the water at the start of the cycle. The remaining margin of increase is due to the presence of some industries with wastewater of high conductivity, although these are small companies, the impact of which is diluted by the overall effluent of urban origin. This water, appropriately treated using conventional procedures, can be used for practically any irrigation use and for any industrial application.

Conversely, the annual average conductivity of the water in the collector on the industrial estate is close to 3,000 µS/cm due to the activity of numerous textiles companies operating in the wet treatment branch of the industry, several of which are large in size, with a generalised lack of water recycling or treatment prior to discharge. In fact, discharge water with conductivity of over 5,000 µS/cm is frequent, although this is not authorised in municipal bylaws. The mixing of this water with water from the urban centre generates effluent from the WWTP with an average conductivity of some 2,200 µS/cm and with other pollutant loads, the discharge of which causes serious problems in the river Clariano and complicates irrigation further downstream.

It is interesting to note that, while industrial discharge generates over 90% of the salt load of the waste water of Ontinyent and similar proportions of all the other pollutant loads, payment for drainage in the industrial sector only represents around 34% of the total, with the remaining 66% falling to the domestic and commercial sectors, which are responsible for scarcely 10% of the pollutant loads.

Attempts at industrial water reuse in Ontinyent, in order to reduce pressure on the La Umbría aquifer, which supplies the city and is highly over-exploited, are coming up against the problem of salinity. In effect, the current high levels of conductivity when the water leaves the treatment plant are generated from high-quality water at the start of the cycle from the La Umbría aquifer, whose conductivity is under 600 µS/cm. If industrial waters were to be reintroduced into the cycle with conductivity levels of 2,200 µS/cm following tertiary treatment, all of the salinity parameters in the cycle would be changed, and various stages of the textile production cycle could be affected.

In Ontinyent the salinity cycle was analysed quite exhaustively in different reuse settings. The successive cycles of salinity feedback were simulated, showing that the grade of reuse permissible for industrial processes was very low, of just 3,000 m^3/day, that is no more than 20% mix for an industrial demand of around 15,000 m^3/day. At levels above this percentage of reuse, excessive salinity levels were reached in the industrial water. Moreover, there is the problem of the irregularity of the conductivity of wastewater, which presents sharp increases as a consequence of certain industrial discharging. These sudden increases can affect the cycle as a whole and cause unforeseen problems in some textile processes, with the possibility of serious economic effects.

In light of these results, the reuse programme is at present being re-evaluated, and the introduction of a reverse osmosis stage is under consideration to remove some salinity from the system. This solution could make reuse viable, but at a high cost and creating a new and serious problem of reject brine discharge in an inland location into a river with low flow levels, such as the river Clariano.

This is yet again a question of “end-of-pipe” solutions that could have been avoided if reuse had been considered with the global cycle in mind. For this, all that was required was for the substantial investments made recently for the extension of the unified WWTP of Ontinyent/Agullent (finished in 2001) to be focused on the separate treatment of urban and industrial effluent and on the separation of industrial discharge that causes deterioration to waste water from the urban centre. In this way urban waste water with tertiary treatment could have been reused in its entirety (8,000 m^3/day) in industry without any problems whatsoever, as its conductivity could have been maintained very stably at around 900 µS/cm.

In Alicante similar problems are occurring as those described for Ontinyent, in addition to others specific to coastal cities, which mean that the conductivity levels reached by wastewater are extremely high. The main WWTP (Rincón de León, which treats some 30 hm^3/year) receives wastewater from two lines, which are treated separately. 50,000 m^3/day (18 hm^3/year) arrive through the first (line A), with a conductivity of 2,500 µS/cm and 32,000 m^3/day (12 hm^3/year) arrive through the second (line B) with a conductivity of 4,500 µS/cm. The WWTP of Monte Orgegia treats around 25,000 m^3/day (8 hm^3/year) with a conductivity of some 3,000 µS/cm (Lapuente, E., 2005).

Such high conductivity is caused by various factors, some of which are little known. Significant saline intrusion has been detected in the collectors on the coastline, in particular in the tourist areas of San Juan and L'Albufereta, which are served by the WWTP of Monte Orgegia. It is possible that, as in numerous places in the Canary and Balearic Islands, some hotels in the area have their own small desalination plants, which then dump the resulting brine into the sewage system. In the Rincón de León WWTP, saline intrusions may affect line A, but they do not appear to do so to any great extent. It is this line that has higher levels of salinity, and it is the more specifically urban line, which means that its saline content appears to come fundamentally from decalcifiers and intensive uses of water that are commercial or residential in nature.

However, of greater seriousness are the intrusions and anomalous saline levels of line B, due it would seem to aquifers or brackish runoff water in the zone of Villafranqueza on the northern edge of the city. Moreover, this line collects industrial wastewater with high salinity in San Vicent del Raspeig, and the brine produced by the brackish water desalination plant of the Institute of Water of the University of Alicante is discharged into this. At the time of the installation of this small desalination plant (450 m^3/day) almost ten years ago, the need for brine conveyance was considered to remove this brine, but its construction has as yet not been tackled.

RECLAMATION TREATMENTS. MEMBRANE TECHNOLOGIES

Depending on the quality of effluent and the use to which it will be put, the treatments necessary will be more or less intensive and costly. When the water entering the WWTP has high levels of dissolved solids at levels above those permitted for the anticipated reuses of the water, conventional treatment processes are insufficient and it is usually necessary to resort to membrane technologies.

Membrane technologies are processes activated by the hydraulic energy associated with the feed liquid and are based on different types of membrane. At present, these technologies are usually classified as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). Another membrane technology, activated in this case by electrical energy, is electrodialysis reversal (EDR). The distinction between these technologies is made according to the size range of the particles that they are capable of separating, determining different values governing operating pressure, the combination of operating mechanisms, and the associated cost per unit of permeate produced. A brief outline of the five technologies mentioned is given below. The first two techniques function mainly using the physical phenomenon of filtration, while for the latter three the phenomenon of diffusion or adsorption is of greater importance.

Microfiltration

Microfiltration is effective in the separation of all types of suspended solids, large bacteria and colloidal particles larger than 0.1 µm. The basic separation method is filtration, although in a lower proportion the MF membranes also work using adsorption and diffusion, rejecting a small quantity of salts.

Ultrafiltration

UF membranes are effective in the separation of organic molecules with a high molecular weight, bacteria and viruses, and in general all particles of a size greater than 0.01 µm. The basic operating method is still filtration, but separation rates for large divalent and monovalent ions are greater due to the more important role played by diffusion. This process is becoming increasingly significant in the pre-treatment stage of desalination by RO.

Nanofiltration

NF is effective for the separation of divalent ions (e.g. calcium and magnesium), large monovalent ions and organic molecules in general. Due to the small pore size of its membranes and the predominance of the diffusion mechanism, it can separate any particle greater than a nanometre (0.001 µm) in size. NF membranes contribute to a major improvement in the hardness caused by the dissolution of calcium and magnesium, which means that they are also known as membrane softeners.

Reverse Osmosis

RO membranes are effective in the separation of all those substances rejected by the previous membranes, including the smallest constituents, such as the monovalent ions of sodium and chlorine. The almost exclusive mechanism is diffusion. The size of the pores of the membranes is 0.00005 microns, although this figure is for information only and in this case it is more appropriate to talk of molecular structures or networks than of porosity.

Electrodialysis reversal

Electrodialysis reversal separates electrically charged ions using the application of an electrical field to the water to be purified. The charged ions pass through membranes of cationic or anionic exchange, depending on their respective charge, which enables their separation. The size of the pores is around one nanometre, similar to that of nanofiltration. Due to its greater resistance to contamination, EDR is often the technology of choice for the reclamation of wastewater with high levels of salinity.

Both in the peninsular Mediterranean regions and on the islands, the agricultural reuse of urban water increasingly requires the use of membrane technologies to prevent problems of soil salinity and the loss of crop productivity. The most used technologies are reverse osmosis and electrodialysis reversal, although in many cases prior processes of microfiltration or ultrafiltration are used to protect the reverse osmosis membranes.

Reverse osmosis treatments carried out on waste water with a salinity of 3,000 µS/cm usually result in water of excellent quality with conductivity levels that can be under 400 µS/cm. Rejects and brine vary between 12% and 20% of water on entry. Costs are relatively high, higher than for RO or EDR treatments themselves, due to the pre-treatment and conditioning operations which must usually be carried out. In the case of low-quality entry water, it is possible that the integral treatment of the waste water, including reverse osmosis, can be greater than the desalination of sea water, especially if it is good quality seawater.

In Alicante the main deficit in hydrological resources is in Medio Vinalopó, an area specialising in the production of packaged grapes. Grape vines are fairly sensitive to salinity and can show signs of reduced production at conductivity levels of 1,000 µS/cm in irrigation water. As a result of the problems detected several years ago due to the direct use of water treated in the WWTP of Rincón de León on various crops, construction work has begun on a post-treatment plant for urban waste water in order to reclaim the 50,000 m^3/day of line A, which has a salinity level of 2,500 µS/cm.

The process begins with an ultrafiltration treatment applied to the full entry flow (50,000 m^3/day). This leads to the almost total elimination of suspended solids (from 30 mg/l to undetectable).

A part of the microfiltered water (25,000 m^3/day) is treated using reverse osmosis, which generates some 20,400 m^3/day of osmosed water. The remainder is brine, which is dumped in the sea. 4,600 m^3/day of ultrafiltered water is added to the osmosed water, resulting in 25,000 m^3/day of water with a conductivity level of some 600 µS/cm being obtained, that is, very high quality water.

The salinity of the non-osmosed ultrafiltered water (some 20,000 m^3/day) remains at 2,500 µS/cm, which means that this water is only suitable for crops with high salinity tolerance.

The cost of the investment is 14.7 million euros and the maintenance cost of the system reaches 2.044 million euros per year, for an annual production (counting the high and low quality water) of some 16 hm^3, which represents operating costs of some 0.13 €/m^3, plus amortisation costs of 0.04 €/m^3, not including financial costs, and supposing that the plant operates at full capacity throughout the year (Serrano, V., 2005).

CONCLUSIONS

The correct use/quality adjustment for reused water is one of the key factors in the success of reuse programmes. To reach a good level of adjustment, with minimum costs, the applications of water when it is reused must be borne in mind from the outset of the urban use cycle. In this way, throughout the water cycle decisions can be made that generate improvements in final effluent, which would in turn reduce as far as possible the need for post-treatments or special treatments for obtaining reclaimed water.

The evolution of the quality of water throughout the urban use cycle, from the natural source to reuse at the end of the cycle, is a process with clear negative feedback. The low quality of water on entering a phase in the cycle usually results in either behaviour or forms of use of the water that intensify the deterioration process of the water during this phase, providing significantly more deteriorated water at the next stage, thus creating a spiral of deterioration.

Paradoxically, the increase in the efficiency of water use in urban systems is usually accompanied by greater deterioration in water quality, in particular in terms of salinity. As a result, in high efficiency urban systems it is necessary to ensure that water is of the highest possible quality on entry to the cycle, so that on exit from the system, the water is still in a condition that enables the avoidance of costly post-treatments.

The consideration of waste water as a resource is a necessary prerequisite for the adoption of measures that prevent the additional and unjustified deterioration in the quality of waste water in its journey from the point of entry of used water flows to the treatment plants. Drainage networks must be designed and managed with a criterion of waste water protection and even, as far as possible, so that the journey to the WWTP results in improvements and not further deterioration in the quality of the waste water.

In matters of salinity, the sum of incorrect decisions throughout a complete water cycle can result in the generation of effluent that is useless for any purpose if it does not first undergo reverse osmosis or electrodialysis reversal, which in addition to their high economic cost, result in the loss of a significant portion of the resource in the form of rejects. Conversely, a chain of correct decisions throughout the cycle can generate reclaimable resources of a high quality, suitable for practically any use, applying only conventional treatment techniques, and with considerable savings in costs and resources in the global cycle.

Alicante has amassed a series of unique situations and experiences in water reuse, in particular with regard to the agricultural use of water. From the beginning of the water cycle, little or no attention is paid to the question of protection of quality with a view to future reuse. Problems appear from the beginning of the cycle, with the TSA design concept and the post-transfer system, which mean that the sulphates from the Buendía reservoir, in the upper waters of the river Tagus, are distributed throughout most of the Mediterranean seaboard, from Sagunto to Almería, mixing with other salt loads from different rivers. The city of Alicante is very efficient in the use of water, which contributes to the increased salinity of its effluent, but in addition to this, the drainage network is affected by a series of discharges and intrusions which seriously impairs the quality of the wastewater arriving at the treatment plants.

The first attempts to reuse wastewater in Alicante in a generalised way and with no other treatment than the conventional secondary treatments failed mainly in the 1980s and 1990s due to the excess salinity of the water. The consequence of this has been the need, in order to make possible the agricultural use of treated waste flows, to implement costly membrane post-treatment of waste water, based on ultrafiltration and reverse osmosis. In this way it becomes possible to reclaim part of the wastewater that is high in quality and suitable for all types of irrigation. However, it must be asked whether the same, or better, results, could not have been obtained at lower cost by applying successive protection criteria to the water for reclamation throughout the water cycle.

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