Towards sustainability in water recycling

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Abstract Those like us who believe in and spread the gospel of planned wastewater reclamation and reuse usually emphasize that this is a step towards sustainability in water resource management, but this is something that is very seldom analyzed. This paper discusses, from a critical point of view, issues such as goals in water reuse and influence on water demands, ecological analysis of the cycle of the main pollutants, health aspects and treatment requirements, energy consumption and measurable environmental benefits, in order to provide a set of criteria to assess sustainability in water recycling projects and to decrease the impact of the cultural water cycle on the environment.
Keywords Energy consumption; nutrients; recycling; sustainability; water reclamation

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Background

In a world of increasing water demand and increasing pollution of water bodies, wastewater reclamation and reuse is also becoming an increasingly regarded practice worldwide. From a theoretical point of view, it addresses both problems, by combining water supply issues (thus reducing the net demand, especially in coastal areas) and water pollution control issues (reduction of discharges into the environment), with an acceptably low risk for human health if properly planned and implemented. In an age in which recycling and sustainability are two of the key reference points – the latter being utopian most of the time – when talking about environment and resource management, we wanted to explore, from a critical point of view, some kind of criteria to help define sustainability in water recycling.

The Consorci de la Costa Brava (CCB, Costa Brava Water Agency, Spain) has been working in the field of wastewater reclamation and reuse since 1985, when it organized the first Spanish conference on this topic. In the year 2002, the flow of wastewater with treatment beyond secondary level reached 2.6 hm^3/year out of 30 hm^3/year of total production. Reclaimed water on the Costa Brava has a variety of uses, including golf course and landscape irrigation, agricultural irrigation, environmental enhancement, urban non-potable uses and aquifer recharge. The ideas herein presented are mostly based on what has been learnt over these last 18 years on the Costa Brava in terms of water reuse and water resource management.

The natural water cycle versus the cultural water cycle

As opposed to the natural water cycle, the cultural water cycle derives from human activities. Human modifications on the natural cycle have caused profound alterations to it and there are only a few completely natural water bodies in the world, mainly located in remote areas with few human settlements. Thus, the water cycle in our societies is strongly influenced by human intervention through the construction of water collection and distribution devices (dams, irrigation channels, wells) and through the deterioration of quality in pristine waters through discharges into the waterways (urban and industrial wastewaters, and non-point urban and agricultural pollution). The development of societies from being mostly agricultural to today's patchwork western-style urban planning, in which agriculture, industry, services, tourist activities and, last but not least, environmental protection all coincide, has led to an overall increase in water demand. This water demand has traditionally been met with water from the best source available. However, over the years and driven by a rationale that has progressively appeared in water sensitive areas (southern California, Israel, South Africa, Australia, Spain), it has become evident that not all uses require the same water quality. Some of these uses can be supplied with water of an inferior quality, which frees the high quality resources for the uses that require higher quality, such as drinking water production. In fact, this is nothing new in the history of mankind, since by 226 AD Rome already had eleven aqueducts and each one had its own quality of water and specific use. Whereas the Aqua Marcia was known for its fresh and cool water, excellent for drinking water purposes, the Aqua Anio Vetus was utilized primarily for public baths, gardens and industry, owing to its poorer quality (Duncan, 2002).

Water reuse as a tool for efficient resource allocation

As a general rule, the most accepted goal for wastewater reclamation and reuse projects is to produce water of sufficient quality to be used for all the potential uses that do not require drinking water quality standards, such as agricultural and landscape irrigation, industrial uses, and non-potable urban uses. These uses would probably free important volumes of freshwater that otherwise would be wasted. According to Okun (1998), only about 15% of water used in urban areas is required to be of potable quality, and since the UN Social and Economic Council stated as early as 1958 that “no higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade”, it is evident that a policy of wastewater reclamation for non-potable uses would be beneficial for many cities and communities. Ideally, water recycling should allow a reorganization of sources and demands, leading to better overall management of water resources.

However, owing to recent improvements in membrane technology, which allow the production of high quality water from any kind of source, considerable progress has been made over recent years in producing reclaimed water for augmenting drinking water supply through artificial aquifer recharge and/or indirect potable reuse, and several projects of this kind have arisen in recent years, especially in southwestern USA. Along with negative reporting from the media and opposition from concerned citizens, some scientists have advocated a more conservative approach, using reclaimed water for those uses which do not have a direct link with drinking water production, and leaving potable reuse projects for situations in which other measures, such as applying water conservation measures, importing high quality water from other sources and developing non-potable water reuse projects, have proven technically or economically unfeasible (Okun, 2000). Despite the fact that the actual situation in many places around the world is that drinking water is produced from freshwater sources which receive wastewater discharges with different degrees of treatment along their course, and which may be of lower quality than many well-treated reclaimed waters, this conservative approach is still a very sound proposal for a safe integration of water reuse into overall water resource management.

Focusing on non-potable reuse projects, their implementation would be of the highest value if they maximized the release of higher quality water to be re-allocated to the most valuable use in the area. Whereas in developed countries these high value uses tend to be drinking water production and/or environmental enhancement, the situation in developing countries would more likely be to increase the availability of water for agricultural irrigation. Benefits of water reuse on the environment will be even greater should these projects be implemented in parallel with programs of demand management. Reversing the universal – and, stunningly, undisputed – upward trend in total demand by identifying non-essential consumptions (conceptually similar to the idea of demerit goods in the economy, such as wet gardening in semi-arid areas, unfortunately a situation of increasing relevance in the

Mediterranean basin), combined with sound wastewater reclamation and reuse programs, would lead to an important step towards sustainability in water resource management. An example of how wastewater reclamation and reuse and demand management can effectively allow a re-allocation of resources and lead to better management can be seen in the Muga river basin, in northern Costa Brava, where a stable overall demand and planned water reuse for agricultural irrigation would provide greater flows and improve the ecological condition of this river (Consorci de la Costa Brava, 2000).

Ecological analysis of the cycle of the main pollutants

Wastewater treatment has always been considered from the point of view of the reduction of wastewater components that are more likely to have an adverse effect on the environment, more specifically on the receiving water bodies. Because they are in larger quantities and their negative effects have been readily observed, wastewater treatment has traditionally been aimed at reducing the concentrations of organic carbon (to avoid dissolved oxygen depletion) and nitrogen and phosphorus (to avoid eutrophication). However, the analysis of the cycle of these main pollutants and the adequacy of their actual fate from an ecological point of view is very seldom made. In order to have the best pollution control – and thus the most beneficial environmental effect – wastewater treatment should place each pollutant in the ecological compartment with the lowest adverse impact (Table 1). In wastewater treatment, the organic carbon is decomposed by microorganisms in both water and soil (when biosolids are recycled) and assuming that wastewater is treated aerobically, the final sink of the CO_2 produced is the atmosphere. Organic carbon cannot be recycled through secondary producers and must necessarily return to the ecosystems through the uptake of atmospheric CO_2 by primary producers (vegetables).

In contrast, from the ecological perspective, the best sink and most stable form for nitrogen and phosphorus is to become part of the biomass (Sala and Mujeriego, 2001). Despite the fact that a portion of these elements are already being recycled when biosolids are applied to land as fertilizers, nitrogen and phosphorus in water have other fates than recycling if water is not being reused. Nitrogen is mostly released to the atmosphere through denitrification, and to receiving water bodies through effluent discharges, whereas the remaining phosphorus can only be discharged to water bodies through effluent, since its biogeochemical cycle does not have an aerial phase. If reclaimed water is used for irrigation, both nitrogen and phosphorus are being recycled through vegetable uptake, which may lead to important fertilizer savings and to a reduction of eutrophication in the receiving water bodies.

In the case of nitrogen, its recycling would also save energy, since it is required for the production of mineral nitrogen fertilizers from atmospheric molecular nitrogen (N_2). A sound proposal for a maximum benefit of parallel water and nitrogen recycling has been presented by Hatziconstantinou and Andreadakis (2003) for locations such as the Mediterranean region, where there is major wastewater production in summer because of tourist activities, and also a high water demand for irrigation. In the case of phosphorus this would be of even greater importance since world phosphorus reserves are limited and dwindling (Steen, 1998), and current waste management practices tend more towards its loss rather than its conservation; in other words, we are turning a resource into a pollutant. However, the trend seems lately to be changing, and the phosphate industry is leading the warnings about phosphorus depletion and encouraging phosphorus recycling (CEEP, 2001). At a research level, important efforts are also being made to recover phosphorus from animal and human waste (Duley, 2001).

Health aspects

A controversial debate which usually takes place at international water recycling conferences concerns regulations and quality of reclaimed water. Whereas in developing countries the WHO guidelines are seen as the logical ones, in developed countries, regulations governing reclaimed water quality are becoming increasingly restrictive, with a recent trend to require reverse osmosis in water to be dedicated to uses with a high potential degree of human contact, such as groundwater recharge. What some scientists see as a gap that has to be overcome is, in fact, the present reflection of different socio-economic realities that would probably converge over time, but at a much slower rate than would objectively be desirable from the standpoint of general human well-being.

In relation to the microbiological aspects of wastewater reclamation and recycling, Anderson *et al*. (2001) have explained in detail the two opposing views currently held in the water reuse sector: the "high technology/high cost/low risk approach" of the developed world and the "low technology/low cost/controlled risk" of the developing world, and how the latter has not always been achieved in practice because of insufficient resources or poor practice. To overcome this gap, Anderson *et al*., propose the creation of an international recycled water quality framework, with a series of steps progressing from "low quality/high risk" to "high quality/low risk", and aimed at guiding developing countries on what the next step should be in order to lower the risk levels of water recycling. However, the authors state that these international guidelines should provide additional information on the match between different qualities and risks, and also provide guidance

Table 1 Fate of the main urban wastewater pollutants according to present treatment practices and best possible fate from the ecological point of view

Element	By-product	Present fate (according to common practices)	Best possible fate (where feasible)	Comments
Organic carbon (BOD)	Water	Atmosphere (CO_2)	Atmosphere (CO_2)	Direct large scale recycling of organic carbon in wastewater through secondary producers is not possible. It needs to be released to the atmosphere by the action of decomposers and returned to the ecosystem through the uptake of CO_2 by primary producers.
	Biosolids	Atmosphere (CO_2) biomass	Atmosphere (CO_2) biomass	
Nitrogen	Water	Atmosphere (N_2) receiving water bodies	Soil/plant	Nitrogen removal to the atmosphere through N_2 has no negative impact (78% N_2 in composition), but it does not stimulate nitrogen recycling and leads to an increase in energy consumption for fertilizer production. Risks of eutrophication are increased because of the constant consumption of first-generation nitrogen (chemical fertilizers). By recycling the N in the biosolids, the loop is closed and there is a net decrease in the consumption of this element and possibly some energy savings. The nitrogen that is released to the environment has undesirable effects of eutrophication and bio diversity reduction.
	Biosolids	Soil/plant (biosolids recycling)	Soil/plant (biosolids recycling)	
Phosphorus	Water	Receiving water body	Soil/plant	By recycling the phosphorus in the biosolids, the loop is closed and there is a net decrease in the consumption of this element. The phosphorus that is released to the environment has undesirable effects of eutrophication and biodiversity reduction. Recycling needs to be encouraged, since this is a non-renewable resource.
	Biosolids	Soil/plant (biosolids recycling)	Soil/plant (biosolids recycling)	

on management practices in order to keep risk under control, something that has yet to be done.

In furtherance of this idea, we propose that the quality of reclaimed water should be in relation to the socio-economic level of each area, in a way that bears some relation to the sanitary level of the population and to the degree of risk posed by drinking water supply. If that was the logic behind the initial Title 22 regulations in California, this could still be the logic in developing countries in order to define what the level of treatment and quality should be. Obviously, in certain areas this would require the acknowledgment that drinking water has some degree of microbiological pollution, but it would put the requirements in a reasonable context and would also allow – and in some way force – improvements in reclaimed water quality if there is such an improvement in drinking water quality. For example, following the rationale of Californian regulations, the draft of the Spanish regulations on water recycling is consistent with the vision that reclaimed water for the most restrictive uses has to be of near-potable quality in terms of microbiological limits, which is consistent in turn with the overall sanitary level of the population. In an area with a poorer public health, where probably the financial resources are limited too, it simply would make no sense to regulate for such a degree of quality in reclaimed water quality when there would be far more important issues to solve (i.e., quality of drinking water), thus making sanitary decisions based on an efficient allocation of available funding. Summarizing the concept, water recycling should preferably be based on real risk assessment, taking into account quality, uses, practices and sanitary level of the population, rather than solely on reclaimed water quality.

Energy consumption

Water is a renewable resource, but a large portion of the energy sources currently used are not. Thus, from a sustainability point of view, energy savings are probably far more crucial than water savings themselves. The addition of a reclamation step for treated wastewater increases the energy consumption of the facilities where it is being implemented. This increase is related to the intensity of the reclamation treatment to be applied to the secondary effluent, and it will vary from almost nothing for simple chlorination to a greater consumption when the treatment includes costly steps such as UV disinfection or reverse osmosis. Analyzing this issue from the standpoint of sustainability – i.e., taking the decisions which have the lowest overall impact on the environment – we may find that implementing reclamation treatment with reverse osmosis in a given community may be a waste of energy – and, ultimately, money – if the provision, treatment and distribution of drinking water has a low energy consumption. In this case, a better management option may be encouraging conservation in the community, in order to save water, energy and taxpayers' money. Instead, as revealed by a recent survey of the energy consumption of different sections of the water cycle (drinking water collection or withdrawal, treatment and distribution, wastewater collection and treatment, and reclamation of treated wastewater) in several municipalities of the Costa Brava (Serra and Sala, 2003), it was concluded that wastewater reclamation and reuse generally appeared as an energy-saving resource when drinking water had an associated high energy consumption, because of either withdrawal (deep wells), treatment (desalination) and/or transportation (when pumping over long distances or to high elevations is needed between the treatment plant and the municipal storage tanks) (Table 2). Therefore, these kinds of calculations may be essential in order to ascertain which set of measures will have a greater benefit for the environment.

Though not directly measuring energy consumption, Frederick (1995) reaches similar conclusions and states that in the US a major portion of the cost of recycling wastewater is spent on the treatment for pollution abatement (to discharge effluents into water bodies

Table 2 Comparison of the energy consumption of the different sections of the water cycle in the municipalities belonging to the Costa Brava Water Agency (adapted from Serra and Sala, 2003)

Type and source of water	Range in energy consumption kWh/m^3
Drinking water supply (transportation to main storage tanks included)	
Surface water	0.0002–1.74
Groundwater	0.37–1.32
Desalination	4.94–5.41
Biological wastewater treatment	
Activated sludge	0.43–1.09
Extended aeration	0.49–1.01
Waste stabilization ponds	0.05
Reclamation treatment for pathogen removal (a)	
Direct filtration (pulsed bed filters) plus UV disinfection	0.18
Direct filtration plus UV disinfection	0.50–1.21
Title-22 with UV disinfection	0.20–0.63

(a) Consumption of the distribution of reclaimed water not included owing to its high variability depending on the user location

without adverse impacts), whereas the marginal costs of reclamation treatment for unrestricted agricultural use, and of storing and conveying the upgraded water to the user, are competitive with alternative sources of new supplies in many areas.

Positive externalities

Any water recycling project leads to the reduction of discharges into the environment. If reclaimed water is treated accordingly there is no exception to the rule that all water recycling projects produce positive externalities, which are seldom accounted for beyond the classical ones regarding the increased availability of water resources in a given area. Whilst the economic measurement of these positive externalities has yet to be resolved, they are frequently overlooked even from the environmental point of view, since focus is mostly placed on water recycling itself. Some of these positive externalities may be related to public health, to landscape quality, to improvement of habitats for local flora and fauna and to restoration or recreation of ecosystems such as wetlands.

Examples of these externalities which are being measured in water recycling projects in the Costa Brava area include the estimation of the reduction in nutrient discharges to the environment, which account for 25 tons of nitrogen and 6 tons of phosphorus recycled every year (Nieto *et al*., 2001), and the marked improvement in the microbiological quality of the bathing waters of the beach at the mouth of the Muga river, in Castelló d’Empúries. This beach has changed from not being swimmable (years 1991 – first year of microbiological monitoring – to 1994) to being swimmable (1995–1998) after the construction of the Empuriabrava WWTP, and to having bathing waters of the highest microbiological quality (years 1998 to 2000 and 2002), after the implementation of the water reuse project for environmental purposes at the Aiguamolls de l’Empordà Nature Reserve.

The determination and measurement of positive externalities of water recycling should be encouraged, in order to give a broader view of the benefits brought by this kind of project. In this regard, the regular monitoring of the composition and abundance of benthic invertebrate fauna, as requested by the new EU Water Framework Directive (European Union, 2000), would probably help uncover some of the environmental benefits of future water recycling projects.

Conclusions

Though it has often been said that water recycling is a step towards sustainability in water resource management, it has seldom been analyzed in detail from this perspective. Water recycling projects will most likely contribute to greater sustainability when:

1. there is effective management of the total water demand, allowing re-allocation of resources and producing real freshwater savings;
2. the main pollutants in wastewater are being placed in the ecological compartment with the lowest adverse impact on the environment;
3. treatment levels and reclaimed water quality correspond to the social and economic situation of a given community and are neither unrealistic nor pose an increased health hazard for the population;
4. the energy consumption of water recycling (reclamation plus distribution) is lower than that of some drinking water sources, so both water and energy are being conserved;
5. the positive externalities are being measured.

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