A New Paradigm for Water Resource Management

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Introduction

The United Nations International Conference on Water and the Environment, held in Dublin, Ireland, in January 1992 (ICWE, 1992), formulated four principles, two of which established basic criteria for water resource management in the 21st Century: "Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment" and "Water has an economic value in all its competing uses and should be recognized as an economic good..."

These two principles have shaped all subsequent decision-making on water resource management, stimulating parsimonious use of water and lending the element the connotations of "commodity". In Brazil, the response has come through the promulgation of wide-reaching legislation, including Law n. 9,433 (January 1997), which instituted the National Water Resource Policy and defined the legal and administrative framework for the National Water Resource System; law n. 9,984 (July 2000), which created the National Water Agency; and Conama Resolution n. 16 (May 2001), which established general criteria for authorizing the direct use of water resources.

Law n. 9,433, which establishes that "a charge will be payable upon water resource uses subject to authorization" (art.20, section IV), substantially modified the operational and economic bases of water use.

Charging for water use, though criticized by certain sectors, including opinion-formers in the environmentalist milieu, has become an extremely beneficent tool both in terms of conserving water resources, as it leads to management of demand, and of environmental protection, as it promotes the reduction of effluent discharge into water bodies.

However, this measure of a legal and institutional character will not be enough to maintain the balance between water supply and demand, especially in major urban areas with prospects of population and industrial growth, where water supply is already insufficient under current conditions.

Water Resource Criticality Index rates (WRCI), associated with the specific availability of water resources (m^3/person/year) in a given region or watershed, shown in Table 1, reflect the water resource management problems that can occur where demand begins to outstrip supply (Falkenmark, 1992).

Note that availabilities in the region of 10,000 m^3/per/yr (WRCI 1 and 2) do not generate any significant conflicts in terms of water quantity. However, availability in rate categories 4 and 5 reflects unsustainable situations of conflicts of use and chronic water scarcity. Management experience has shown that Specific Water Availability (SWA) values above 1,700 m^3/person/year correspond to situations of hydric sufficiency, while values below 1,700 indicate the risk of water scarcity and values under 1,000 confirm chronic water shortages.

In average terms, Brazil enjoys a highly favorable situation, with 33,944.73 m^3/person/year (ANA, 2002). In the state of São Paulo, the average relative value in 1996 was 3,014.4 m^3/person/year, with a reduction to 2,339.6 expected for 2010 (IBGE, 2000). Given the tendency toward continued population and industrial growth, water availability will decline over time, though water availability per se tends to remain fairly constant (in terms of flow, but not in terms of quality).

A closer look at the situation reveals that water availability conditions are extremely critical. In the Upper Tietê basin, for example, home to the São Paulo Metropolitan Region, specific availability is currently 216.7 m^3/person/year, with a value of under 179.3 m^3/person/year expected for 2010. The Piracicaba/Capivari/Jundiaí Riverbasin, which supplies 33 m^3/s to Metropolitan São Paulo, currently holds stocks of 497.46 m^3/person/year, though these are expected to fall to 347.2 m^3/person/year by 2010 (IBGE, 2000).

Table 1

Water Resource Criticality Index (WRCI). Specific Water Availability (SWA) and associated problems (Falkenmark, 1992)

WRCI	Specific Water Availability (SWA) (m^3/per/yr.)	Water resource management problems
1	SWA 10,000	No or limited problems
2	10,000 > SWA 2,000	General management problems
3	2,000 > SWA 1,000	Heavy pressure on water resources
4	1,000 > SWA 500	Chronic water shortages
5	SWA < 500	Beyond availability limit

The old paradigm

Today, water availability in Metropolitan São Paulo, considering all water imported from surrounding and distant basins, is no longer sufficient to meet the demand of a population now bordering on twenty million people and one of the largest industrial parks in the world. Decision-makers responsible for water supply to the metropolis are studying the possibility of obtaining additional volumes just to keep up with the growing demand. All of the proposals analyzed, without exception, propose the escheatage of basins as a solution. At the beginning of discussions, the most likely candidates were the Capivari-Monos Riverbasin, relatively nearby, and the Ribeira de Iguape Riverbasin, some one hundred kilometers away from Metropolitan São Paulo. The Capivari-Monos has emerged as being practically unviable for political, institutional and environmental reasons, while the Ribeira de Iguape, at least in the early stages of viability studies, presented strong probability of success.

The project envisaged a total reversion of 105 m^3/s, beginning with a flow of 30 m^3/s. However, with capital costs of US$807,797,058 and running costs of US$ 68,491,176 per year in electrical energy for transport and pumping alone, the project was considered unviable and subsequently abandoned (Sampaio, 2005). However, given the relentless growth in demand in the Metropolitan Region, the plan may need to be resurrected in the next few years. Various other options were also considered, such as the option designated D, which deemed viable the possibility of supplementing supply to the Metropolitan Region using 19.4 m^3/s of additional flow from a series of works in the Guarapiranga System (optimization of the Guarapiranga/Taquacetuba), Tietê System (closing the Taiaçupeba and optimizing operations), the Juquitiba System (Juquiá/Juquitiba), Rio Grande System (Rio Pequeno Wing), Upper Tietê (Itapanhaú) and Itatinga System (PDAA, 2006). No other considerations were made by the decision-makers, who ignored the additional sewage volume that would be generated by the adduction of a further 19.4 m^3/s – estimated at approximately 15.5 m^3/s of wastewater, assuming a coefficient of 80% return -, which would certainly be discharged, without treatment, into the already extremely polluted waters of Metropolitan São Paulo.

The policy of importing water from basins further and further away to fill the gap between supply and demand dates back over two thousand years. The Romans, whose domestic water use was intensive, initially tried to capture water from nearby springs, but as these grew increasingly more polluted with untreated sewage or failed to meet growing demand, they had to look for the next closest source, over and over again. This practice gave rise to the construction of the huge Roman aqueducts, the ruins of which can still be seen scattered about the Old World.

The Roman Empire built eleven aqueducts, totaling 502 kilometers in length and channeling some 1,127,220 m^3/day (13,046 L/s). The first of these, the Aqua Appia, was built in 312 BC by Appius Claudius Caecus and C. Plautius. It was only sixteen kilometers long and carried some 73,000 m^3/day (845 L/s). The Aqua Claudia, the construction of which began under Caligula in 38AD and was completed by Claudius in 52, was 69 kilometers long and channeled 184,220m^3/day (2,132 L/s). The biggest of all Roman aqueducts was the Aqua Marcia, at 91 kilometers long and with capacity to conduct 187,600 m^3/day (2,171 L/s) (Swansea University, 2006; Bowdoin College, 2006).

The current systematic is, therefore, the same as that adopted for the last two thousand years, predicated upon resolving the water shortfall of one region, however precariously, to the detriment of the region that provides the supply. As

ABCD. Amplitudo, & forma Speluncæ, ad conſtruendum in eâ Aquæductũ in ipsâ rupe excauatæ

Altitudo C A eſt ped. v. & ſemis. Latitudo C D altitudini æqualis

Fornix minimùm, & vix ſemipede attollitur; nec lateribus Ductus innititur, ſed vi ſuâ ſtat

E F. G H. Latera ex lapide

Figure 1
Transversal section of the Aqua Appia, built in 312 BC, with a mere 16 kilometers in length and flow of 73,000m^3/day (845 L/s)

Figure 2
The Aqua Claudia, built between 38 and 52 AD, measuring 69 kilometers in length and channeling a volume of 184,220 m^3/day (2,132 L/s)

the systems for catchment, transport, treatment and wastewater discharge are not expanded in proportion to the adduced influx, the result is an increase in pollution in the receptor region. There is therefore a pressing need to adopt a new paradigm to substitute the Roman method of systematically transporting large volumes of water from increasingly more distant catchment basins and then dumping the sewage, with little or no treatment, into nearby water bodies, thus rendering them even more polluted than they already were. Figure 1 shows some of the characteristics of the first aqueduct ever built while Figure 2 shows the remnants of the Aqua Claudia, the most famous aqueduct constructed by the Romans.

The new paradigm

Without counting losses in the systems of production and adduction, average total demand for the São Paulo Metropolitan Region in 2005 was 68.1 m^3/s, and the estimate for 2010 is for 71.9 m^3/s (PDAA, 2006). Assuming rather arbitrarily that the flow currently distributed in Metropolitan São Paulo is 70 m^3/s, using a coefficient of 80% return, we can estimate that this new inflow will yield approximately 56 m^3/s of sewage to be disposed of in the region.

The capacity currently installed at the five sewage treatment stations on the Tietê Project in Metropolitan São Paulo (Barueri, ABC, Suzano, São Miguel and Parque Novo Mundo) is 18m^3/s. Up to 2007, the volume of flow effectively treated was a mere 10.7 m^3/s, though with the Pomar raised station now operational, this has risen to 13.5 m^3/s, approximately 24% of the volume of sewage actually generated (Lorenzi, 2008). This 4.5 m^3/s shortfall on installed capacity comes down to the total precariousness of the planning that went into the implantation of the sanitary system in Metropolitan São Paulo, which allowed the construction of the treatment stations to run ahead of the construction of the interceptors and collection trunks.

These figures show just how serious the sanitation situation is in Metropolitan São Paulo. Of the 56 m^3/s of sewage that is produced only 13.5 m^3/s are treated. That means that 42.5 m^3/s of raw sewage are continuously discharged back into the receptor water bodies.

Despite the effort that has been made and the significant investment of human and financial resources, Metropolitan São Paulo has still not managed to solve the basic environmental problem that other large international capitals *on the same economic level* succeeded in resolving in the 20th Century, namely the removal of sewage from the urban area. Practically the whole hydric system installed in the metropolitan region, including the Tietê, Pinheiros and Tamanduateí rivers, receives this considerable inflow of raw sewage, with some stretches presenting anaerobic and aesthetic conditions incompatible with the modern setting of the largest urban conglomerate in the country.

The systematic channeling of large volumes of water from far-off sources, generating additional volumes of sewage, is simply no longer acceptable, whether economically or environmentally. Effectively, the capital costs associated with the new systems tend to be far higher than the relative costs of the existing systems, largely because the closer and less polluted waterheads have already been developed. A study conducted by the World Bank, analyzing the resources invested in international water supply projects, showed that the cost per cubic meter of potable water on the "next" project could be two to three times that of the previous one, as shown in Figure 3.

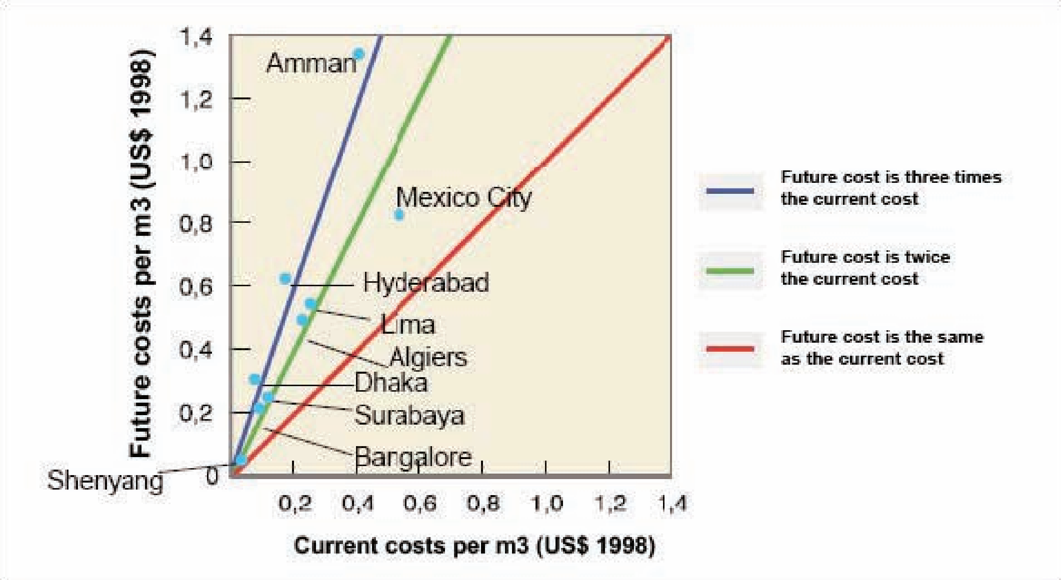

Figure 3
Costs of existing water supply systems versus the costs of new projects

This systematic, associated with the paltry investment in sewage collection and treatment systems typical of developing countries, promotes an increase in water-body pollution, as shown in Figure 4, due to reduced concentrations of dissolved oxygen in the water (World Bank, 1992).

We must also consider the legal and politico-institutional problems that go with inter-basin re-routing. This practice is becoming increasingly more restrictive in the face of popular environmental awareness, tougher water resource entities and the institutional development of basin committees in the regions being drained of these valuable hydric resources.

In terms of water resource management, it is therefore fundamental, especially in urban areas, that we abandon the outmoded orthodox principles and implement a new paradigm based on the key-words of *water conservation* and *reuse*, as only thus will it be possible to minimize the costs and environmental impacts associated with the new channeling projects. Conservation should be promoted through demand-adapted management and environmental education programs, while reuse should be geared toward the management of supply, searching for new supply alternatives, including recuperated water, rainwater and groundwater, and complemented with artificial aquifer recharge.

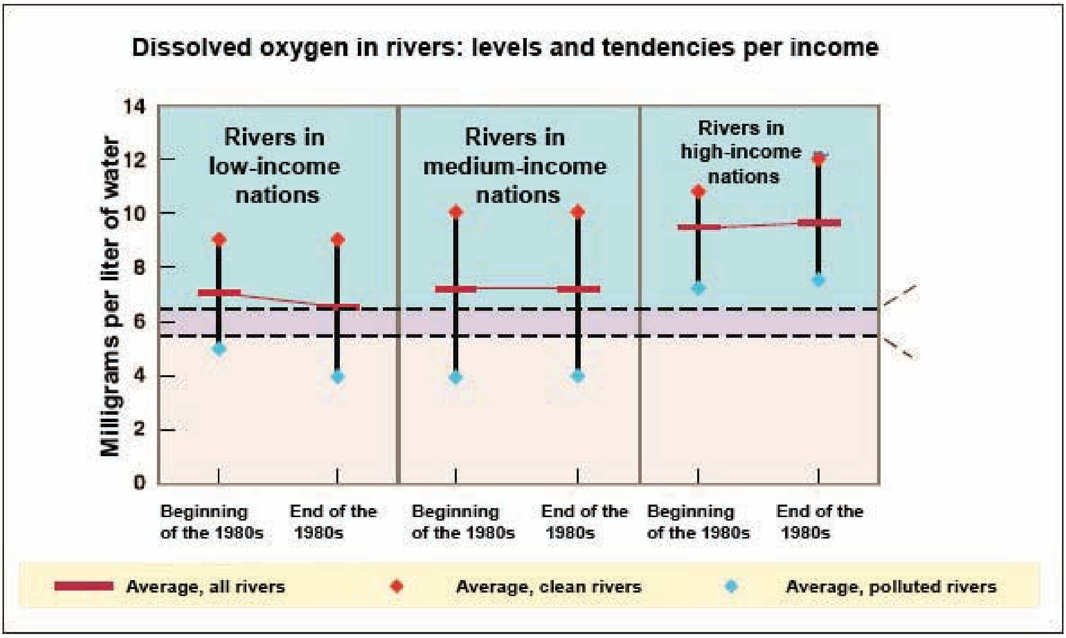

Figure 4
Upward trend in pollution (measured in dissolved oxygen) in developing countries, due to the relatively low rates of investment in sanitation, compared with downward pollution trends in industrialized nations.

In the case of Metropolitan São Paulo, for example, one can safely say that no more than 30m³/s of the 70m³/s adduced will be put to potable use. The remaining 40m³/s represent the potential for reuse in the Metropolitan region, and could be substituted with reused water for non-potable domestic uses (toilet flush, floor washing, etc.), non-potable urban uses, such as the cleaning of streets and vehicles, the irrigation of green areas and sports pitches, civil construction and industry and, moreover, in the replenishment of nearby aquifers which, in a short span of time, will be on the brink of collapse due to intensified predatory demand from industry and commercial and residential buildings. Implementing this approach on a large scale will make it unnecessary to channel water from any of the basins under consideration in order to supplement supply to the Metropolitan region. Effective action to control losses and programs to encourage water conservation will make an additional contribution to increasing the existing water availability and reducing the growing demand in the region.

The need for reuse

The lack of hydric resources and the escalation of conflicts for water use have generated an emergency need for water conservation and treatment and reuse as formal components of water resource management. The benefits inherent to the use of recuperated water for purposes other than discharge, include the preservation of high-quality sources, environmental protection and economic and social gains (Asano et al., 2007).

In arid and semi-arid regions, water has become a limiting factor on urban, industrial and agricultural development. Water resource planners and administrative entities are looking for new water sources to meet the growing demand, especially in the domestic and industrial sectors. In the polygon of droughtzones in the Northeast, the sheer dimensions of the problem are underscored by an eighty-year eagerness to re-route the São Francisco river in order to bring water to the non-riparian states of the semi-arid region, located to the north and east of the watershed. Various countries in the Middle East, where average rainfall oscillates between 100 and 200mm per year, depend on a handful of perennial rivers and small groundwater reservoirs, mostly located in hard to reach mountainous regions. In many countries, potable water is obtained through the desalination of seawater, while the impossibility of sustaining irrigated agriculture means that 50% of staple foodstuffs is imported to meet basic demands (Hespanhol, 1999).

However, the practice of water reuse is by no means restricted to arid and semi-arid regions. Many other areas with abundant water resources, but nonetheless insufficient to meet excessively high demands, could also experience water use conflicts and curtailed consumption, in turn hampering economic development and quality of life. As already considered, the Upper Tietê basin, as a waterhead, has insufficient water availability to meet the demands of Metropolitan São Paulo, despite average annual precipitation of roughly 1,490 mm/year (PMSP, 2001).

Foreseeing the need to modify orthodox water resource management policies, especially in more well-endowed regions, the United Nations Economic and Social Council (United Nations, 1958) proposed, as far back as 1958, that "unless there happens to be vast availability, no quality water should be used for any purpose for which lower quality waters would suffice". Lower quality waters, such as domestic wastewater, effluent from water and industrial effluent treatment stations, agricultural run-off and brackish water, should, whenever possible, be considered alternative sources for less restrictive uses. The application of appropriate technology for the development of these sources constitutes, today, alongside a series of improvements in the efficiency of usage and demand management, the basic strategy for solving the problem of a universal lack of water.

With a view to tackling the environmental challenges of the 21st century, Agenda 21, a basic document drafted by the United Nations Conference on the Environment and Development, held in Rio de Janeiro in 1992 (UNCED, 1992), also placed great store on reuse, recommending that its member states implement management policies geared toward the use and recycling of effluents and the integrated protection of the public health of high-risk groups through adequate environmental practices.

Chapter 21 – "Environmentally Sound Management of Solid Wastes and Sewage-related Issues", Programme Area B – "Maximizing environmentally sound waste reuse and recycling", established the following as basic principles: "To strengthen and increase national waste reuse and recycling systems" and "To make available information, techniques and appropriate policy instruments to encourage and make operational waste reuse and recycling schemes".

The practice of reuse is therefore directly and indirectly associated with chapters 12 – "Managing Fragile Ecosystems: combating desertification and drought"; 14 –"Promoting Sustainable Agriculture and Rural Development"; 18- "Protection of the Quality and Supply of Freshwater Resources: application of integrated approaches to the development, management and use of water resources", which envisages water availability "for sustainable food production and rural development" and "for the protection of water resources, water quality and aquatic ecosystems"; and Chapter 30 – "Strengthening the Role of Business and Industry", which proposes - in Programme Area A – that member governments should "increase the efficiency of resource utilization, including increasing the reuse and recycling of residues, and reduce the quantity of waste discharge per unit of economic output".

Brazil remains bereft of any legal framework to regulate, orient and promote the practice of water reuse, and this is perhaps the most significant deficiency currently hobbling the universalization of the practice in our country (Hespanhol, 2003a). However, in December of the same year as the ECO-92 conference, the item "Resource Conservation and Management for Development" (Paragraph 64/B) of the Inter-Parliamentary Conference on Development and the Environment, held in Brasília, recommended that efforts be redoubled nationwide to "institutionalize the recycling and reuse of water whenever possible and promote the treatment and disposal of wastewater in such a manner as does not pollute the environment" (Inter-Parliamentary…, 1992). After this show of political will, little was actually done whether in legal or institutional terms to promote the practice of water reuse in Brazil.

The last positive step in the sector was taken on November 28, 2005, when the National Water Resource Council (CNHR) promulgated Resolution 54, which "establishes the modalities, directives and general criteria for the direct reuse of non-potable water". Today, the CNHR is in the process of drafting specific procedures for reuse (industry, agriculture, aquiculture, urban non-potable uses and managed aquifer recharge), though there is no scheduled date for the official publication of this legislation.

Forms of reuse

The total quantity of water available on the earth for the last five-hundred million years is of approximately 1.4 billion km^3. Though this is a finite volume, the hydrological cycle ensures that water is a renewable resource and therefore permanently available. When recycled through natural systems, water is a clean and safe resource, though anthropic activity has seen this deteriorate into various degrees of pollution. However, once polluted, water can be recuperated and reused for various beneficial purposes. The quality of the water used and the specific objective of reuse will establish the levels of treatment recommended, the safety criteria to be adopted and the capital and running costs of all associated maintenance. The possibilities and potential forms of reuse depend, obviously, upon the local characteristics, conditions and other determinants, such as political decision-making, institutional schemas, technical availability and economic, social and cultural factors. Figure 5 presents the basic types of potential use of treated wastewater that could be implemented in urban and/or rural areas (Hespanhol, 1999).

Whatever the form of reuse employed, it is essential to observe some basic principles that guide the practice, namely: the preservation of the users' health; the preservation of the environment; consistent compliance with the quality standards established for the intended reuse; and the protection of the materials and equipment used in the reusage system (Hespanhol, 2002).

Urban uses

In urban areas, the potential reuse of wastewater is ample and diversified. However, uses that demand water of a high quality require advanced treatment and control systems, which often entail costs incompatible with the corresponding benefits. In general, treated sewage can be used for potable and non-potable purposes in the urban context.

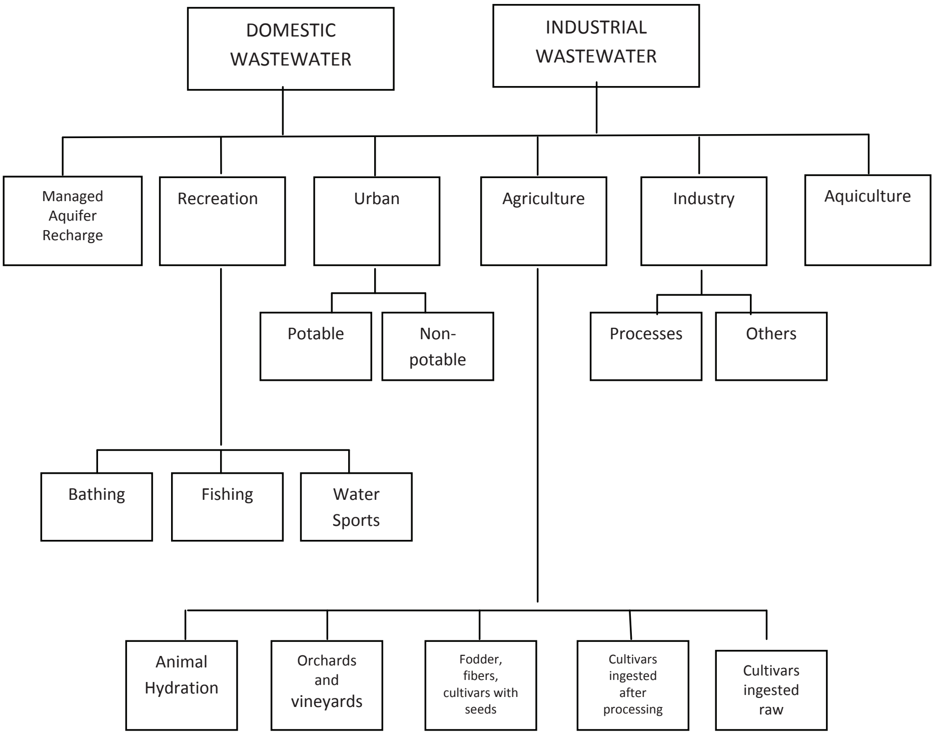

Figure 5 – Potential forms of water reuse.

Potable urban uses – The presence of pathogenic organisms and synthetic organic compounds in the vast majority of effluents available for reuse, especially those from sewage treatment stations in large urban centers with industrial hubs, classifies potable reuse as an extremely high-risk and practically unviable alternative. According to Metcalf & Eddy (2003), three factors of special interest could limit the supply of reused water for potable purposes: the presence of enteric viruses, organic constituents, including industrial chemicals, residential residues, medications and heavy metals. The effects these various constituents might have on human health are still not well known, which is why environmental regulation agencies worldwide proceed with great care when it comes to permitting reuse for potable purposes. These problems were aggravated recently with the discovery of so-called "emergent pollutants" (endocrinal disruptors, active pharmaceutical agents, cryptosporidia, girardia, and many others) in waterheads used for public supply and even in distribution networks for potable water. Traditional and emerging compound substances, such as those found in industrial effluents, are not removed by the conventional water treatment systems used in Brazil (coagulation/flocculation, sedimentation, filtration and disinfection using chlorine), and could cause serious problems to users of public water supply lines.

Furthermore, the costs of more advanced water treatment systems that could handle these substances would render public water supply economically/financially unviable, besides the abovementioned problems concerning any guarantees of adequate health protection for the consumer.

Non-potable urban uses – Many sanitation companies are currently preparing themselves to supply so-called "reuse water" or "utility water" to cater for non-potable water uses in the urban area. This practice, already widely disseminated in many metropolitan areas throughout Brazil, especially in Metropolitan São Paulo, consists in complementing water treatment using biological systems with physico-chemical processes and making the supply available in limited areas for diverse uses and, particularly, to new users. The raw material for non-potable urban reuse is basically domestic wastewater. However, there have recently been discussions on the possibility of using clear greywaters for non-potable reuse in urban areas, especially in residential apartment blocks and condominiums.

Reuse of domestic effluents

Reuse for non-potable urban purposes is characterized by the employment of treated domestic wastewater to supply various demands that require waters below potable grade. Non-potable urban reuse is subdivided into two categories: areas of controlled access and non-controlled access. Special care must be taken when it comes to direct contact with the public (Usepa,2004; Hespanhol, 1997). The main applications in this case are:

- Irrigation of public, residential and industrial parks and gardens, sports centers, football pitches and golf courses, school and university campus gardens, lawns, and decorative trees and shrubbery along avenues and streets;
- Fire brigade water reserves;
- Decorative aquatic systems, such as fountains and water mirrors;
- Washing of vehicles, including cars, trucks, buses and trains;
- Washing of flooring, grounds and patios;
- Toilet flush in public restrooms and in public and private residential and commercial buildings;
- Washing of sewage pipes and rainwater galleries;
- Dust control;
- Civil construction, for washing aggregates, preparing and curing concrete and controlling humidity for soil setting.

Greywater reuse

In addition to the reuse of domestic wastewater, it is also possible to use some specific components generated in buildings, such as light and dark greywater.

Some darker greywaters is domestic wastewater from which toilet effluents have been removed. It is therefore water derived from lavatories, showers and baths, kitchen sinks and washing machines (Jefferson et al., 1999; Eriksson et al., 2002; Ottoson & Stenstrom, 2003). Lighter greywaters also come from residential sources, but with the exclusion of all lavatory or kitchen effluents, which have high levels of organic content due to the presence of quickly degradable compounds, such as oils and fats (Nolde, 1999; Christova-Boal et al., 1996).

Treated lighter greywaters are now beginning to be used in Brazil, as they cost less to treat than domestic sewage due to their lower organic load and presence of fewer pathogenic organisms.

Properly treated greywater does lend itself to certain non-potable reuses. With a relatively stable year-round flow, as it is easy to collect and, given its lower concentration of organic load and thermotolerant organisms, requires a less rigid level of treatment than domestic wastewater. There will be variations of quality depending on the source, that is, whether the water comes from lavatories, washing machines or showers. According to a quality evaluation conducted in Brazil (May, 2004) and Turkey (Santos & Zabracki, 2003), greywaters contain high volumes of organic matter (which could cause odor or altered taste), high nitrate levels (an indication of toxicity) and turbidity (presence of suspended solids) (May, 2004; May & Hespanhol, 2006).

Greywater, once properly treated, can be put to the same non-potable uses as domestic wastewater.

The use of greywater is directly linked with such factors as quality of the effluent, the treatment applied, and, especially, the end use to which it is put.

Water reuse systems should be designed and constructed to be sustainable and eco-efficient. These factors are usually ascertained through socio-economic and environmental analyses prior to the implantation of the reuse system, so as to ensure a project that can meet all the safety requirements.

However, the reuse of greywater depends upon the following conditions if it is to be practical and economical:

- Reuse systems in apartment/office buildings ought to take into account the costs and operational problems associated with duplicating a large portion of the building's hydraulic system (for separated collection of greywater and its internal distribution as toilet flush, for example). Even in new buildings, the need to use partially duplicated hydraulic systems significantly increases costs;
- In the case of collection through public or private networks (in condominiums, for example), in addition to the household costs mentioned above, it is also necessary to evaluate those incurred through the construction of an additional network to collect effluent from lavatories and kitchen sinks.

Reuse for irrigation

Irrigated agriculture has become one of the most important economic activities in Brazil in recent years. Irrigation and the drainage of irrigated fields are activities that enable the farmer to counter the negative effects of bad distribution, both spatial and temporal, of rainwater. In 2002 (Christophidis, 2002), the total area of cultivated land in Brazil was estimated at 54 million hectares, of which only three million were irrigated. However, this small percentage was responsible for 14% of all national agricultural production. Today, the total cultivated area in the country is 77 million hectares, though the irrigated portion has remained in or around the three million hectare mark.

Through irrigation, agricultural production can be intensified, regularizing the year-round availability of food stocks, as the practice makes it possible to continue production even out of season. Irrigation is the biggest consumer of water of all the uses to which this natural resource is put, though the volume used will largely depend on the method employed. Soil type, the requirements of different crops and local rates of evaporation are key to determining water consumption through irrigation.

The Brazilian agricultural sector accounts for 70% of total water consumption nationwide, though this will likely reach 80% by the end of the decade. The reasons for the increased use of wastewater for irrigation over the last few decades have been:

- The difficulty in identifying alternative water sources for irrigation;

- The high costs of fertilizers;
- Assurances that wastewater use in irrigation posed minimal risk to public health or soil quality if the proper precautions are taken;
- The high costs of the treatment systems necessary to dispose of effluents in watercourses;
- Socio-cultural acceptance of the practice in agriculture;
- Recognition by water resource management organs of the intrinsic value of the practice.

Effluents from conventional treatment systems, such as activated sludge, normally have total N content of 15mg/liter and total P concentrations of 3mg/liter, which, at normal rates for irrigation in semi-arid zones (approximately two meters per year), amounts to an annual N and P input of 300 and 60kg/ha, respectively. This injection of nutrients substantially reduces or even eliminates the need for commercial fertilizers. Besides the nutrients (and the micro-nutrients not provided by synthetic fertilizers), the application of wastewater also adds organic matter to the soil, which functions as a conditioner, increasing water retention capacity.

Increased productivity is not, however, the only benefit of applying treated effluents in agriculture, as it becomes possible to enlarge the irrigated area to such an extent that, when climate conditions allow, multiple harvests can be made practically all year round (Hespanhol, 1990).

One notable example of economic recovery associated with the availability of wastewater for irrigation is that of Mesquital Valley in Mexico, where agricultural incomes increased from near zero at the beginning of the century, when sewage from Mexico City was first made available at posts region-wide, to approximately four million US dollars per hectare in 1990 (CNA, 1993).

Studies conducted in a range of countries all show that agricultural productivity increases considerably under irrigation systems using properly treated effluents. Table 2 shows the results of experiments carried out in Nagpur, India, by the National Environmental Engineering Institute (Neeri), which investigated the effects of wastewater irrigation on crop yields (Shende, 1985).

Table 2
Increased agricultural productivity (ton/ha/yr) made possible through irrigation using domestic wastewater.

Irrigation using:	Wheat 8 years(A)	Beans 5 years(A)	Rice 7 years(A)	POTATO 4 years(A)	COTTON 3 years(A)
Raw sewage	3.34	0.9	2.97	23.11	2.56
Primary effluent	3.45	0.87	2.94	20.78	2.3
Effluent from stabilization ponds	3.45	0.78	2.98	22.31	2.41
Water + NPK	2.7	0.72	2.03	17.16	1.7

Number of years used to calculate average productivity

Properly planned and managed reuse systems bring about improvements in the environment and in public health, especially in rural areas in developing countries. Some highly positive aspects of sewage reuse in agriculture are outlined below:

- Avoids discharging the sewage into water bodies;
- Preserves underground resources, especially in areas where the overuse of aquifers causes saline intrusion or subsidence in the terrain;
- Allows for soil conservation through the accumulation of humus, increases resistance to erosion and boosts soil water retention capacity;
- Particularly in developing countries, it contributes to increased food production, thereby boosting the health levels, life quality and social conditions of the populations benefitted by reuse schemes.

That said, certain detrimental effects are also associated with the use of sewage in irrigation. One potentially negative consequence is the pollution of underground aquifers used for public supply with chemical substances, particularly nitrates and pathogenic organisms. This occurs when an unsaturated, highly porous layer rests atop the aquifer, allowing nitrates to percolate through. When the upper part of the aquifer consists of a deep and homogeneous layer with capacity to retain and process these elements, the chances of contamination are negligible. Nitrogen assimilation by potted plants, for example, reduces the possibility of nitrate contamination, but this depends on the plants' rate of assimilation and the amount of sewage applied to the soil.

The accumulation of chemical contaminants in the soil is another potentially negative effect. Depending on the characteristics of the wastewater, the practice of irrigation over long periods of time can lead to the accumulation of toxic organic and inorganic compounds and a significant increase in salinity in unsaturated layers (Foster et al., 1994). To avoid this possibility, irrigation should be done using wastewater of a predominantly domestic origin. The need for an adequate draining system must also be borne in mind in order to minimize the process of salting. Likewise, the application of sewage over long periods could give rise to habitats propitious to the proliferation of vectors of disease, such as flies and some species of snail.

Industrial reuse

Industry today is bearing the brunt of two heavy instruments of pressure. On one hand, there are the global impositions - both environmental and health-related - resulting from domestic and foreign trade relations; and, on the other, there are the recent legal stipulations on water resource management, particularly in association with charges on water use (Pio, 2005).

In order to adapt to this new situation, industry has been fine-tuning its processes and developing environmental management systems in a bid to meet the specifications of the domestic and foreign markets, as well as implementing procedures designed to manage water demand and minimize the generation of effluents (Mierzwa & Hespanhol, 2005).

These factors, associated with high water costs, have led industry to assess the possibility of internal reuse and to consider offers from the sanitation corporation to buy treated effluent at lower prices than the potable water available through the public supply system. "Utility water", produced by the treatment of secondary effluents and distributed through mains serving large clusters of companies, has now become a very attractive option for industrial supply at a reasonable price. In Metropolitan São Paulo, for example, the water normally made available to industry costs US$5.70 per cubic meter, while utility water represents a marginal cost of under US$1.20. This rate varies depending on local conditions, both in terms of levels of necessary additional treatment and the distribution network. The presence of sewage treatment stations in the environs of industrial zones contributed to the implantation of reuse programs, as it made utility water distribution systems compatible with industrial demand a much more viable prospect.

Given the criteria of establishing priorities for uses that require high volumes and relatively low treatment levels, in accordance with the needs of the industrial processes, it is recommended that the initial phases of the industrial reuse program concentrate on cooling towers.

Though it corresponds to a mere 17% of non-potable water demand by industry, the use of treated secondary effluents in cooling systems has the advantage of requiring the same levels of quality across the board, regardless of the type of industry, and of being suitable for other, less restrictive uses too, such as for washing floors and equipment and for use in mechanical and metallurgical processes. In addition, the quality of water suitable for cooling semi-open systems is also compatible with other non-potable urban utilities, such as the irrigation of parks and gardens, the cleaning of public streets and roads, civil construction, and the formation of lakes for recreational and landscaping purposes. Other uses that could be considered in later phases of the implementation of an industrial reuse program include water for vapor production, flushing gases from chimneys and for other specific industrial processes in the metallurgical, primary metal smelting, tanning, textiles, chemical, petrochemical, paper and cellulose, plastics and civil construction industries (Silva et al., 2003). These modalities of reuse would require advanced treatment systems and therefore higher levels of investment.

Water conservation in the form of demand management should also be encouraged in industry, pressing for the adoption of modern industrial processes and washing systems with lower water requirements, as well as water treatment stations for public supply through the adequate recuperation and reuse of water used to wash filters and decanters.

The basic applications of reused water in industry are (Hespanhol & Gonçalves, 2005. Adapted):

- As a cooling or heating agent; in these cases, the water is used as a heat transmitter removing heat from reactive mixtures or other devices that need cooling, or due to the established operating conditions, where high temperatures might compromise system performance or damage equipment;
- As raw material in industrial processes;
- As an auxiliary fluid, such as in the preparation of chemical suspensions and solutions, intermediary compounds, chemical reagents, vehicles or even for cleaning operations;
- Use in energy generation: the potential or thermal energy in the water can be transformed into mechanical and electrical energy;
- As flush water in toilets and urinals;
- In civil construction, painting cabins, fire-fighting, sprinkler systems, or incorporated into sub-products generated by industrial processes, whether in the solid, liquid or gaseous states.

The quality of water for industrial use will depend on the purpose for which it is intended. In most cases, the effluent requires additional treatment over and above secondary treatment, thus achieving the level of quality required for some industrial uses.

Managed aquifer recharge

The practice of artificially replenishing aquifers, known as Managed Aquifer Recharge (MAR), using treated domestic wastewater has found applications in various parts of the world, both in arid and semi-arid regions and in areas with high hydric availability. In Brazil, this still little-known practice has evoked the ire of hydrologists, biologists, environmental engineers and conservationists in general, who consider it a methodology that poses a high risk of contaminating groundwaters.

Natural aquifer recharge occurs directly through rainfall and run-off from rivers, lakes and reservoirs. Natural recharge obviously occurs without any control or selection and may actually end up polluting underground aquifers. The most critical condition occurs when recharge is influenced by unplanned and inadvertent anthropic activity, submitting aquifers to contamination through infiltration and/or lixiviation associated with the use of biosolid effluents or fertilizers and biocides in the soil. It also occurs through the infiltration of organic and inorganic micropollutants present in degraded areas or in fuels and animal fats from landfills or open-air garbage tips.

With a view to increasing water availability and perhaps even resolving localized problems, water resource engineering developed managed recharge technology, which uses appropriately treated effluents. This allows for the replenishment of groundwater stocks much more quickly than would naturally occur, therefore affording greater security in terms of aquifer protection, as the quality of the recharged waters is adequately monitored.

Artificial recharge, seen as a modality of reuse, could cater to a gamut of important purposes, such as (Hespanhol, 2006):

- *Providing additional treatment to effluents*
  Infiltration and percolation of treated effluents would benefit from the soil's natural capacity for biodegradation, absorption, hydrolysis, precipitation, complexation, ionic exchange, filtration, etc., providing in situ treatment and – given the type of effluent used, the methods of recharge, the hydrological conditions and expected use - helping eliminate the need for more advanced treatment systems. The treatment provided by the unsaturated layer and the aquifer per se is called Soil-Aquifer Treatment, or SAT. The replenishment process also helps diminish the association between treated effluents and groundwater, reducing the psychological impact of reuse for diverse beneficial ends.
- *Increasing water availability in potable and non-potable aquifers*
  This is one of the prime advantages of artificial recharge, particularly in areas lacking in water resources. The transformation of sewage into water of sufficient quality to cater for beneficial uses, such as irrigation, also constitutes an environmental benefit, as it avoids effluent spillage into water courses.
- *Provision of water reservoirs to substitute surface reservoirs*
  Some water uses that present seasonal demand require large reservoirs for storage or alternative methods of discharge during periods of low demand. These reservoirs, when built aboveground, take up large surface areas and entail high costs. Besides the environmental impact they cause, these surface reservoirs are also affected by pollution, evaporation, the development of unpleasant tastes and odors due to the proliferation of algae, the excessive production of macrophyta and other problems that incur further running and maintenance costs.
- *Allow the aquifer to serve as a system of distribution, thus eliminating channels or trunk lines*
  Depending on local conditions, the infiltrated water recovery basins can be located in various critical demand flashpoints, thus allowing for a reduction of costs associated with distribution and stabilization ponds.
- *Prevent soil subsidence*
  Soil subsidence, defined as "the consolidation or sinking of soil due to loss of underlying support", is a problem in areas where there is an excessive pumping of aquifer stocks without commensurate natural recharge. The recharge of aquifers affected by subsidence eliminates or minimizes this phenomenon.

- *Prevent saltwater intrusion in coastal aquifers*
  The excessive pumping of groundwater from coastal aquifers can cause an in-seep of saltwater, rendering the aquifer unsuitable as a potable water stock and for other uses that cannot tolerate high levels of salinity. Injection wells and Infiltration basins can be built in critical areas, creating barriers against saline intrusion. Treated effluents are injected into the confined aquifers, where they establish a sea-bound hydraulic gradient that blocks seawater from penetrating into the aquifer.

The most commonly used methods of managed aquifer recharge are direct injection using specially built wells or infiltration basins. For direct recharge, it is necessary to treat the effluents to potable levels in order to protect the integrity of the aquifer (Foster et al., 1994). Considering the costs of treatment plus the costs of boring the wells, the process requires heavy investment. Recharge through infiltration basins is always more economical, as it harnesses the soil's own purifying capacity, therefore avoiding the need for advanced treatments and the construction of injection wells. In this case, it is essential that a hydrological survey be carried out to ascertain the characteristics of layers above the water table and the hydraulic parameters of the aquifer itself, such as composition, porosity, infiltration capacity, among others.

Reuse in aquaculture

The feeding of lakes for the production of fish and aquatic plants using excreta or sewage is a time-tested practice that has endured over centuries in Asia, especially in China, India, Indonesia and Vietnam. The practice is also exercised in Europe (in Germany, since the end of the 19th Century, and in Hungary), in Africa (Egypt and South Africa) (Edwards & Pullin, 1990) and in South America, especially in Peru (Cavallini, 1996). The biggest system still in operation was established in Calcutta, India, in 1930 and currently covers a total lake area of some three thousand hectares, producing between four and nine tons of fish per hectare.

In Brazil fish-farming systems are responsible for enormous fish turnout. Some 150 thousand tons of fish were produced using this practice in 2000. In addition to fish-farming, there are other commercial projects associated with carcinoculture (prawns and crabs) and malacoculture (mollusks). The fish most often bred in Brazil are Nile tilapia (*Oreochromis niloticus*) and catfish (*Pseudoplatystoma sp*) (Crepaldi et al., 2006). Despite this enormous production, there are still no lake systems in Brazil producing aquatic fare of any kind fertilized with treated sewage.

The fish most commonly produced outside of Brazil are various types of tilapia (*Oreochromis niloticus*), the common carp (*Cyprianus carpo*), other carp species (*Catla catlax, Cirrhina mrigala, Labeo rohita, Hypophthalmichthys lolitrix,* *Aristichthys nobilis, Ctenopharyngodon idella, Carassius auratus, Ostechilus hasseltii*, etc.) and the giant Malaysian prawn, also known as the freshwater prawn (*Machrobrachium rosembergii*).

Various edible aquatic plants are also produced in lakes fertilized using domestic waste and excreta, and the most common species are: water spinach (Ipomoea aquatic), sensitive plant (*Neptunia oleracea*), watercress (*Rorippa nasturtium aquaticum*) and Chinese water chestnuts (*Eleocharis dulcis*). Aquatic plants known as duckweeds (lemna, spirodela and wolfia) are grown in some parts of Asia in shallow lakes fertilized with excreta and sewage. Once harvested and dried, these plants are used as feedstock for chickens, ducks and some edible snails. Over the last few decades in Indonesia, a private initiative has been developing a highly lucrative business of growing lemna in lakes fertilized with raw domestic sewage. Lemna, once dried, is used to fertilize lakes for farming fish, especially tilapia. The process is extremely productive and contamination-free, as no sewage or excreta is introduced directly into the fish lakes, which are exclusively fertilized using lemna (Gijzen & Ikramullah, 1999).

The necessary measures to protect the health of groups associated with aquiculture fertilized using sewage and excreta are similar to those for agriculture insofar as they entail sewage treatment, fertilization methods and the control of human exposure. The protection of lake operators is closely related to the quality of the lake water. Transmission of pathogenic organisms can occur through the handling and/or preparation of fish feedstock and aquatic plants. However, sanitary education involving aspects of personal hygiene and adequate handling procedures is extremely important. The treatment given to the excreta and domestic wastewater has to be properly considered, as it has a direct impact on water quality in fish-farm lakes. These aspects become all the more important in regions where fish are eaten raw (Hespanhol, 2003b).

A significant number of helminthes may be present in effluents and excreta used for lake fertilization, and fish and aquatic plants may serve as intermediary hosts. Some trematodes, such as *Clonorchis, Opstorchis, Diphyllobothrium, Heterophys* and *Metagonimus*, are among the most frequent. However, it has been verified that only *Clonorchiasis* (liver fluke) and *Opistorchiasis* can be transmitted by fish raised in lakes fertilized with excreta or sewage. The first stage in the development of these organisms occurs in specific snails, with some fish species serving as intermediary secondary hosts. Some other helminthes, such as Fasciola and Fasciopoli, have similar life cycles, but prefer aquatic plants as intermediary vectors, especially watercress (*Rorippa nasturtium aquaticum*), Chinese water chestnuts (*Eleocharis dulcis*) and water cucumber.

Water snails of the genera *Biomphalaria* serve as intermediary hosts for the trematode *Schistosoma*, which causes schistosomiasis or bilharziasis. Transmission occurs when the cercariae bore into the operators working the lakes through direct contact with the skin.

Fish and plants raised in lakes fertilized with excreta and sewage may also be contaminated with bacteria and viruses that can be passed on to humans if the foodstuff is not properly cooked. Bacteria and viruses can also be contracted passively through the gills or through intraperitoneal liquid of the digestive tract or edible muscle of fish.

The World Health organization (WHO, 2006) established the following directives for aquaculture fertilized with sewage and excreta:

- geometric average of E. *coli* per 100ml or per gram of solids lower than 10^4 in lakes to prevent bacterial invasion of fish meat and lower than 10^3 to protect operators and the local community. The same value should be observed in lakes producing edible aquatic plants (macrophyta), as in some nations these are eaten raw. This concentration can be obtained by supplying lakes with treated sewage with maximum E. *coli* concentrations of 10^4 and 10^5per 100 ml, assuming that the dilution of the lake itself is of proper magnitude. This directive applies only to invasion of organisms into fish muscle and does not therefore remove contamination via the digestive tract or intraperitoneal liquid of fish. This condition can lead to cross-contamination during the preparation of fish for cooking. In this sense, the use of high standards of hygiene while preparing fish for cooking can mitigate the risks of disease transmission;
- the total absence of viable termatode eggs in order to avoid infection by helminthes, such as *Clonorchiasis, Fascialopsis* and *Schistomiasis.* This condition can be achieved through treatment in sequential stabilization ponds, as the eggs of these helminthes are easily removed through sedimentation. Note that the transmission of helminthic infections associated with *Clonorchiasis* and *Fascialopsis* only occurs in certain parts of Asia, and can be easily avoided by eliminating termatode eggs that find their way into lakes or by eliminating the snails that serve as intermediary hosts. In Brazil, control should focus on schistosomiasis, especially where this occurs endemically.

Aspects of bacteria decontamination should be analyzed under particular Brazilian conditions. The practice of keeping fish raised in lakes fertilized with sewage and excreta in clean water holding ponds does little good with highly contaminated fish. In general, purification in clean lakes for a period of one or two weeks has proved ineffective in the decontamination process.

When there are traces of industrial effluents in the sewage used, the possibility of bioaccumulation should be taken into account, especially when it comes to heavy metals and organic micropollutants. Algae developed in lakes have enormous capacity to accumulate heavy metals, with the exception of mercury. However, fish raised in these types of pond do not present cumulative characteristics, probably because the cumulative process requires much longer periods of time than it takes the fish to develop. In general, fish have a certain ability to control the assimilation of heavy metals (except mercury) by their tissues, and tend to accumulate metals in various parts of the body, with the exception of the muscle, which yields much of the edible content.

Reuse for recreation

Recreational activities associated with water include fishing, canoeing, water-skiing and other activities that involve at least minimal contact with the water. Swimming and wading are activities permitted only where water quality meets the legal requisites for total bodily contact and incidental ingestion of water.

One striking example of this type of reuse is the Santee Lake recreational project in Santee, California, USA, which covers a total area of 77 hectares, including 33 ha of lakes. The park receives approximately 550 thousand visitors per year, and despite being fed with effluents subjected to advanced treatments (biological system of activated sludge, nitrification and dentrification, coagulation, flocculation, lamellar sedimentation, filtration, chlorination and chlorine removal using sulfur dioxide), only activities that do not require total physical immersion are permitted. In the initial phase of the operation, the system included a natural swimming pool where swimming and bathing were permitted in the shallows. However, this activity was later suspended because the sandy bed of the pool contributed to increased turbidity of the water, disturbing particles that may still retain some bacterial pathogens (Asano et al., 2007).

The practice of reuse for recreational ends (albeit in a conscious and controlled manner) is still totally inexistent in Brazil, but could perhaps come to be a beneficial use of treated sewage in the future, given the huge and unfulfilled demand for leisure facilities, especially in the large metropolitan regions.

Conclusions and recommendations

Concern surrounding the chronic lack of water is not limited to the semi-arid region, but extends to various metropolitan regions throughout Brazil. Whilst Brazil is home to a considerable percentage of the world's water resources, many regions have to make do with hydric resource stocks of two-hundred cubic meters per inhabitant per year, generating critical water supply shortages and causing conflicts of water use.

- Large urban and industrial hubs like the Metropolitan Region of São Paulo are still using orthodox practices to meet public and industrial demands. In addition to importing 33m^3/s from the Piracicaba Riverbasin, a region now strained to the limit in terms of water resources, decision-makers in Metropolitan São Paulo are planning to adduce a further 19.4 m^3/s from far-off locations in a

> bid to redress the shortfall on local supply. This new channeling will generate approximately 16 m^3/s of sewage, an amount that supersedes the installed treatment capacity currently operating in the region. It must also be remembered that, of the 18 m^3/s of installed capacity, only 13.5 m^3/s is actually treated due to a lapse in the planning and implementation of the local sanitation system. As a result, a further 13.5 m^3/s of raw sewage will be added to the 42.5 m^3/s already discharged *in natura* into the river network of the metropolitan region. That means a total of 58.5 m^3/s of sewage.

So long as the regions considered as viable sources of re-routed water do not themselves possess hydric resources compatible with their needs and so long as the volumes of extra sewage generated are not properly treated and disposed of, the indiscriminate practice of inter-basin re-routing of water resources according to the "old paradigm" cannot be allowed to continue. As the proper conditions are not in place, the only possibility is to adopt a "new paradigm" based on the key words of *water conservation and reuse.*

Industries, particularly in São Paulo State, are already plowing financial resources into the implantation of water conservation and reuse programs, reducing consumption by somewhere between 40% and 80%. Agriculture, which is responsible for something in the region of 70% of total water consumption in Brazil, is beginning to assess the benefits of reuse, which, in addition to irrigation, also endows soils with a significant amount of nutrients, micronutrients and organic material which boosts the water retention capacity of the soil. Other uses, as in aquaculture, managed aquifer recharge and recreational reuses are presently practically inexistent in Brazil.

In order to universalize the practice of reuse in Brazil and truly implement a "new paradigm", the following steps should be taken: (i) develop a legal framework to regulate, guide and promote the practice of water reuse, including norms, water quality standards, codes of conduct and institutional authorities for various different forms of reuse in urban utilities, agriculture, aquaculture, managed aquifer recharge and recreation; and (ii) encourage water reuse by fostering awareness of the values and benefits of the practice, creating research and development programs, implementing programs and projects to disseminate the concept, introducing specific lines of credit for reuse projects , as well as establishing criteria for subsidies. The initiative on these actions could be taken by the National Water Agency (ANA), the Secretariat for Water Resources at the Ministry for the Environment, state water resource departments, basin committees and municipal and state sanitation corporations.

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Abstract - Watershed transposition is a 2000-year-policy developed by the Romans to satisfy their continuous growing water demand, leading to the build up of an extensive network of aqueducts. This is the so called "old paradigm" still prevailing nowadays, for the relief of local water supply constraints on detriment of other regions. The systematic transfer of expressive amount of water from foreign sources, generating extra volumes of wastewater can no longer be accepted, both under economical as well as under environmental aspects. A "new paradigm", based on the concepts of *Water Conservation and Reuse* must evolve, to minimize costs and the environmental impacts associated with watershed transposition. The technology, as well as the basic environmental, public health and operational criteria now available, allow for a full harnessing of local water resources, through water reuse and adequate demand management.

Keywords: Water resources management, Water conservation, Water reuse.

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