Euro-CASE
European Council of Applied Sciences and Engineering

28, rue Saint Dominique - 75007 Paris - France

Tel: +33 1 53 59 53 40 - Fax: +33 1 53 59 53 41
E-mail: mail@euro-case.org - www.euro-case.org

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Content

WASTEWATER AS A RESOURCE – WHAT ARE THE OPTIONS?

Hallvard Ødegaard[*]

[*] *Faculty of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU), N-7491 Trondheim, Norway.* E-mail: *hallvard.odegaard@bygg.ntnu.no*

INTRODUCTION

Control of the epidemics, especially cholera, that ravaged many of the major European cities in the middle of the 18'th century, was the driving force behind the development of wastewater systems. The sanitation conditions had become a threat to the urban human health. Since the introduction of centralised water supply and sewerage systems, the cities of Europe has, however, been essentially free of water-borne epidemics. Around the middle of the 19'th century, discharges of wastewater (sewage as well as industrial waste) for the ever expanding industrialised society, resulted in unacceptable pollution in receiving waters, threatening aquatic life as well as human health. The acceptance of the need for pollution control, leads to the construction of wastewater treatment plants. Today these are taken for granted as part of the infrastructure of a city. Even though people living in the countryside did not experience the epidemics development caused by poor sanitation to the same extent as the cities did, centralised wastewater systems were also established for small communities and villages. Even in scattered dwellings the convenience of using water toilets lead to small on-site wastewater systems that required treatment.

With respect to management of the water resources, the links between the cities and the countryside become ever more evident. The wastewater treatment plants produce sludge and this sludge has to be taken care of in the countryside somehow. The countryside needs water to produce food for the cities, but the cities water is used by the cities that are also polluting the water. This clash of interests has lead to the focus on "Sustainable Urban Water Systems". Two schools of thought have emerged:

1. The present centralised wastewater systems are unsuitable in the future and should be replaced by alternative systems based on local handling
2. The present system is the only realistic one in an urban environment and will be maintained in foreseeable future, but it should be modified to be more in agreement with the principles of sustainable development.

It is very difficult to comprehend how Europe can meet the vast economical consequences of a total system change. Therefore, we have to take our present system as the stepping-stone for a development towards a more sustainable society. Wastewater has traditionally been looked upon as a problem or waste. This work-shop aims at showing that wastewater should rather be regarded as a resource.

RESOURCES IN WASTEWATER

There are principally 3 resource components in wastewater

1. The water itself
2. The heat of the water (energy)
3. The constituents in the wastewater (primarily nutrients and carbon)

When purifying the wastewater, one gets primarily two outgoing streams; 1) the treated water stream and 2) the sludge stream. Both of these streams contain all the three resource components mentioned above, but these resources will be utilised differently depending on in which stream they are present. The water stream is quantitatively much larger that the sludge stream and the water (as such) and the heat of the water is most important. The sludge stream is more important with respect to recovery of nutrients and energy based on its carbon content carbon (biogas, heat from incineration).

REUSE OF THE TREATED WATER

Generally the use of water has been **supply driven**. As it has been an abundant commodity in most places, water has been supplied in large quantities at a very cheap price. This will have to change in the future in many regions that are short of fresh water supplies. The policy of water management is therefore changing from being supply driven to **demand driven.** In a demand driven situation the price of water will increase and it is possible that even extensive treatment of wastewater may turn out to be cost effective in order to produce the necessary amount of freshwater.

There are many possibilities for reuse of reclaimed wastewater, such as 1) for agricultural and landscape irrigation, 2) for urban reuse, 3) for industrial reuse and 4) for potable water supply. The different uses require different degrees of purity of the water, and water quality standards for this has been established (WHO, 1973, 1989). Today there are treatment technologies available that can produce reclaimed water from wastewater for these applications (Mujeriego and Asano, 1999). The greatest challenges in the reuse of reclaimed wastewater are: 1) the safeguarding of the hygienic quality, 2) the prevention of soil contamination and 3) the prevention of ground water contamination.

Reclaimed wastewater for agricultural and landscape irrigation

In most countries the greatest demand for water is for agricultural and urban irrigation. The wastewater resource to be utilised is firstly the water as such and secondly the nutrients in the wastewater. Wastewater purification at "sewage farms" was an example of zero discharge based on the "assimilative" and "self-purification" power of soil (Bouwer, 1993). Even though there are a few remaining of these "sewage farms", the vast area required close to the city as well as health regulations, has made them disappear. After WHO in 1973 proposed unrealistically stringent guidelines for the quality of the effluent to irrigate crops, WHO issued in 1989 new guidelines for aqua-culture and non-potable urban uses. This new set of guidelines is controversial but has allowed a real development of wastewater reuse for irrigation purposes (WHO, 1973, 1989).

Reclaimed wastewater for urban reuse

Urban reuse can primarily be divided in two:

1. Reuse of reclaimed wastewater for toilet flushing in dual distribution systems
2. Reuse of reclaimed wastewater for recreational lakes and brooks as well as for creation of wetlands and wildlife habitat

Dual distribution systems segregate the potable water supply from the non-potable system. Dual distribution systems can be developed in two ways. One approach is to construct a city-wide system in which the wastewater is returned to a central wastewater treatment plant for processing before being redistributed to the population to be used in the non-potable water supply system. The other approach is using small-scale individual systems where "grey" water, the wastewater from washing operations (sinks, bathtubs, showers, wash machines) and other non-faecal wastewater is treated and redistributed to the non-potable water supply system. The latter of the systems have been more extensively used that the first one, caused by the fact that it can be implemented without interfering with the public city water and wastewater system. It is especially used in high-rise buildings, hotels, resorts etc.

The environmental movement has more and more focused on restoring natural environments within cities by establishing or restoring brooks and lakes as well establishing the basis for wetlands and wildlife habitats. For this purpose, reclaimed wastewater (or run-off water) is being extensively more used.

Reclaimed wastewater for industrial reuse

Internal water recycling has been implemented successfully in several industries, while use of reclaimed municipal wastewater is less common. Because of the large volume, reclaimed wastewater can be particularly suitable for cooling-system make-up water, boiler feed water, process waters for various production industries (i.e. iron and steel, textile etc) and wash-down waters (car wash etc). While requirements for irrigation applications tend to vary seasonally, industrial water needs are more consistent. This makes reclaimed wastewater for industrial reuse easier to plan for.

Reclaimed wastewater for potable water supply

Planned direct potable reuse of reclaimed wastewater is seldom used. The most well known is the operation in Windhoek, Namibia (Harhoff and van der Merwe, 1996). This fact is not caused by inability to produce potable water from wastewater or even to the cost of this, but rather by the public acceptance or, more accurately, public rejection of reclaimed wastewater as a potable water supply. The fact that people do not seem to object to reclaimed water from polluted rivers that carries water in which a very substantial fraction originates from sewage, is probably a matter of "not knowing" (as long as I do not know, it does not matter).

Much more common is planned indirect potable reuse in which treated wastewater is discharged to the groundwater, recharging this before used as a potable water source. The purpose of groundwater include: 1) arresting the decline of groundwater levels due to excessive groundwater withdrawals, 2) protection of coastal aquifers against salt water intrusion from the ocean, and 3) to store the surface water (including reclaimed wastewater) for future use (Asano, 1998).

RECLAMATION OF RESOURCES IN THE SLUDGE

The wastewater sludge contains many different components, both valuable resources such as organic matter, nutrients and metals (i.e. residual coagulants), as well as problematic components such as heavy metals and bacteria, virus's etc. The valuable resources in sludge may be reclaimed/reused in three ways:

1. By direct use of sludge on farmland as fertiliser/soil conditioner
2. By use of a constructed soil conditioner (bio-soil)
3. By use of reclaiming resources (energy, nutrients, metals, etc) from the sludge through treatment

Wastewater sludge may turn out to be a very valuable phosphorous source for producing P-fertiliser in the future. In 1989, the Phosphorous Resources Institute of Japan estimated that the phosphate rock in the world would remain for only 50 years at the use of the resources as at that time (Watanabe et al, 2000).

Direct use of sludge on land

In many countries use of sludge on land has been the preferred way of final disposal of the sludge. It both solves a disposal problem for the wastewater treatment plant owners and it has a value for the farmers in terms of the fertiliser and soil conditioner effect. It is technically feasible to treat the sludge to such a degree that it could be used on farm land without any danger, and this direct reuse of the resources in sludge is probably the most sustainable one. Nevertheless, it is a fact that the use of sludge on farmland has been reduced over the years in Europe. This is caused by factors such as; (1) the amount of sludge has exceeded the soil carrying capacity of that region when also the disposal of manure is taken into account, (2) the sludge has contained unacceptably high concentrations of heavy metals, (3) the distance of transport of the sludge to farm-land has been too far to be economically feasible and (4) there has been a fear among the farmer population and the public that food grown on sludge treated soils is not considered safe enough by the public.

In order to deal with the problems of heavy metal accumulation in soil as well as possible hygienic contamination, strict rules and regulations have to be complied with, concerning the pre-treatment of the sludge as well as the area loading of the sludge on the land (Matthews, 1996). In some countries the sludge that is approved for farmland use (for certain crops, such as cereals) has to be disinfected, stabilised and dewatered and comply with maximal values of heavy metal content and content of certain bacteria.

Use of a constructed soil conditioner made from mixtures of sludge and other components

In many regions there is a need for soil conditioner, both for farmland as well as for road/highway embankments, golf courses, skiing courses, parks, football fields, green houses etc. There are now various companies that make a living out of making a soil conditioner for this market by mixing treated (for instance composted) sludge with sand and other filling materials and selling this as a special product (bio-soil etc) that is psychologically not associated with sludge. There is reason to believe that this use of sludge will increase in the future, as the demand for the product is likely to increase.

Indirect use of sludge through the extraction of resources

Constituents that can be reclaimed from treatment of the sludge, are for instance:

1. Energy in the form of:
   - Biogas from anaerobic digestion
   - Biofuel to produce heat from incineration plants
2. Fertilisers in the form of organic C, P and N (the latter from sludge water)
3. Soluble organic matter to be used as carbon source in biological nutrient removal plants
4. Coagulants, from sludge of treatment plants where coagulants have been added

There are several commercially available processes for such reclamation of resources, for instance the KREPRO process developed in Sweden (Cassidy, 1998)

A process that is directly designed for the conversion of sludge to a valuable product is the sludge to oil process in which dewatered sludge undergoes pyrolysis to oil and tar. The tar is used for heating the pyrolysis unit (Campell, 1989) (Steger and Meibner, 1999).

A marketing survey carried out in Northern Europe a couple of years ago, demonstrated that there was a support among wastewater plant owners for the establishment of private companies (sludge reclamation factories) that would be paid to take the sludge and reclaim resources that could be sold in the market place.

EXTRACTING ENERGY FROM WASTEWATER AND WASTEWATER SLUDGE

Wastewater is an energy source. The two major energy sources are the heat of the wastewater and the organic material. The main routes by which the energy potential of the wastewater can be utilised, are:

- By extracting heat from the wastewater through heat pumps
- By producing biogas from the wastewater sludge through anaerobic digestion
- By producing excess heat through incineration of dewatered wastewater sludge

The wastewater as a heat source

The wastewater produced in a city every day is normally cooler in summer and warmer in winter than the outdoor air, making it suitable as a heat source used by heat pumps for heating and cooling. The wastewater of the cities contains enormous quantities of thermal energy. For instance, heat contained in Tokyo's wastewater is estimated at 39 % of the total waste heat, about 10^8 GJ (2,7*10^7 MWh). Using this huge heat source for district heating and cooling in cities by water-source heat pumps can save considerable amounts of energy and reduce SO_x, NO_x and OC_2-emissions. For every kW of electricity used in the heat pumps, 3 kW can be transferred to thermal energy to be supplied to a district heating system. In Gothenburg, for instance, about 25 % of the energy for district heating is recovered from the wastewater. There may be some practical problems encountered when the wastewater is not extensively pre-treated ahead of the heat pump. However, in a scenario where more extensive treatment can be foreseen as a result of the need to reuse water, this is not a serious problem. Such energy reclamation is clearly economically and environmentally feasible and the matter should therefore be more focused in the future.

Production of biogas

There is a long tradition of producing biogas by digestion in the wastewater treatment business, but reduction of sludge mass as well as stabilisation of sludge has been the main objective. Today biogas production is very worthwhile also from an energy and sustainability perspective. The total energy potential from the biogas corresponds to about 2,1 kWh/kg DS of a typical wastewater sludge. This corresponds to about 75 GWh/year in a city of 1 million inhabitants or 15 TWh for the whole of EU's sludge production. Of this energy potential about 1/3 can be recovered as electricity while and about ½ as recoverable heat out of which about 1/6 (of the total) will have to be used for heating the digester. It is evident that the biogas that can be produced from wastewater sludge represents an enormous energy potential and that this potential should be utilised even if the sludge is to be incinerated.

Production of excess heat from incinerators

The raw wastewater sludge has an effective heat value of about 14 MJ/kgDS (3,85 kWh/kgDS) and digested sludge about 12 MJ/kgDS (3,3 kWh/kgDS). Even though anaerobic digestion reduces the amount of sludge and therefore the recoverable heat from incineration, the energy recoverable from the biogas far more than outweighs this. From a recycling point of view, sludge should be digested, therefore, before incinerated. Whether or not one will have an energy surplus from the incineration depends largely on how much water that has to be evaporated (i.e. the DS-content of the sludge to be incinerated). The sludge DS if incoming sludge has to be above about 20 % in order to have a net energy surplus, and this increases drastically with increasing DS-content. Pre-treatment that increase the DS-content at low energy consumption is consequently favourable.

CONCLUSIONS

1. Wastewater should be looked at as a resource with its three main resource components: the water itself, the components of the water (primarily nutrients and carbon) and the heat of the water. Utilization of these resources is closely linked to advanced wastewater treatment
2. In a situation where water use is demand driven, the price of water will be high and extensive wastewater treatment to reclaim water may be cost effective
3. The major use of reclaimed wastewater will be for agricultural and landscape irrigation and for urban reuse (dual distribution systems as well as constructed waterways and wetlands)
4. Utilization of the wastewater heat has a great potential for district heating purposes and should be encouraged
5. Even though direct use on farmland may be the most sustainable way of recycling the resources in sludge, the negative public image of "sewage-fertilized" crops, seems to limit this application in the future
6. The energy that can be produced from sludge biogas is very significant and the use of anaerobic sludge treatment should be encouraged
7. "Productification" of the resources in sludge can be expected - sludge factories will make products such as electricity, heat, biofuel, bio-solids, phosphorous, ammonium etc

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ACHIEVEMENTS AND CHALLENGES IN THE REUSE OF RECLAIMED WATER

Mujeriego, R.

School of Civil Engineering. Universidad Politécnica de Cataluña, Gran Capitán s/n, 08034 Barcelona, Spain. E-mail: rafael.mujeriego@upc.es

INTRODUCTION

Wastewater reuse is an essential component of the natural water cycle. Wastewater discharges to natural watercourses and their subsequent dilution with flowing waters have promoted incidental water reuse in downstream points for urban, agricultural and industrial uses. Direct or planned water reuse at a larger scale has a more recent origin, and implies the direct beneficial use of effluents, with a variable degree of treatment, after water is transported using a specific distribution system, without discharge or dilution in a natural water course.

The considerable development reached by planned wastewater reuse, particularly in areas with sufficient water resources, has been motivated by the need to expand water supply capacity and to improve wastewater discharges. The increase in drinking water allocations, together with the population growth experienced by numerous urban areas, have resulted in conventional water supply sources being insufficient to respond to current water demands. The increasing distances between new water sources and urban centers, the environmental constrains to build new water dams, and the extended drought episodes experienced in some areas have forced numerous communities to approach reuse of reclaimed water as an alternative and additional water source for uses that do not require a potable water quality. Furthermore, increasing public health and environmental requirements on coastal and surface water quality, together with restrictions on location of wastewater facilities and levels of wastewater treatment, have resulted in reclaimed wastewater becoming an alternative water source, economical and safe both from the public health and environmental points of view.

The objective of this presentation is to evaluate the achievements reached by wastewater reclamation and reuse over the last few decades, as well as the challenges that is already facing to become an essential component of water resources management.

WATER RECLAMATION AND REUSE

The treatment process necessary for a wastewater effluent to reach the quality required for a given use is commonly designated water reclamation. The water produced by such a process is known as reclaimed water. The great impact of those words in public perception has resulted in repeated attempts to adopt words with a more positive meaning for public opinion. One of the more significant changes has been the increasing use of the word water, instead of wastewater. Among the current proposals for the processes themselves, repurification and recycling have gained considerable acceptance. Water produced by those processes has been designated repurified and recycled water (Asano, 1991). Asano (2000) has proposed the more symbolic word of “new water” for use in Japanese culture.

Implementation of a water reclamation project has two basic and complementary requirements: 1) to define the water quality limits applicable to the beneficial uses considered, and 2) to establish the treatment processes recommended to achieve the above limits. Beneficial use of reclaimed water requires basically: 1) transport of water from the reclamation facility to the point of use, using a dual distribution pipeline or canal system, 2) an storage facility to adjust water supply and water demand, or an alternative discharge permit when there is no need for reclaimed water, and 3) a set of water use requirements, to minimize potential public health and environmental risks.

BENEFITS OF WATER REUSE

Planned water reuse has made considerable advances in water resources management (Mujeriego, 1998). The most significant contribution has been the realization that reclaimed water is a significant component of the water cycle, to be taken into account together with other more traditional or conventional tools, such as water savings, rational water use, and water demand management. Reuse of reclaimed water may have one or more of the following benefits:

1. An additional contribution of water resources, either as net water resources or as alternative water resources that can be used for beneficial uses not requiring drinking water quality, leaving good quality water to be used for urban water supply.
2. A reduction on wastewater treatment and disposal costs. Reuse of reclaimed water will offer a clear economical advantage when the quality requirements for reclaimed water are lower than those imposed by water quality standards of the water body receiving wastewater effluents.
3. A reduction of pollutant loads to surface water flows, when reuse involves agricultural, landscape or forest irrigation. Irrigation with reclaimed water provides an opportunity for organic substances to be degraded through soil biochemical processes into its mineral components, which can be eventually assimilated by plants.
4. The reduction, postponement, or even cancellation of new drinking water treatment facilities, with the ensuing positive consequences that it may have on natural water courses and water costs.
5. A significant energy saving, while preventing the need for water supplies to be conveyed from areas located much further than the water reclamation facility.
6. A beneficial use of nutrients (nitrogen and phosphorous) contained in reclaimed water, when it is used for agricultural and landscape irrigation. Golf course irrigation with reclaimed water may represent up to Euros 18 000 per year, for a regular championship golf course under southern Mediterranean conditions.
7. A considerable higher reliability and uniformity of water flows available. Urban wastewater flows are normally much more reliable than the vast majority of rivers and streams in semi arid areas, such as the southern Mediterranean region.

REQUIREMENTS OF PLANNED WATER REUSE

One of the determining factors for the implementation and development of planned water reuse is the establishment of water quality criteria and standards for each of the beneficial uses considered (WHO, 1989; USEPA, 1992; WPCF, 1989). Among the numerous substances added to water during its urban, industrial and agricultural use, there are dissolved salts, nutrients, pathogenic microorganisms, inorganic toxic and bio-accumulative substances, and organic micro-pollutants.

To ensure reclaimed water has the highest possible quality, a generally accepted criterion is to use urban wastewater effluents, as first alternative, leaving industrial effluents for exceptional circumstances. According to this criterion, preference is given to wastewater effluents with the largest domestic fraction. To prevent unforeseen pollutants to reach reclamation facilities, disturbing the treatment process and deteriorating its effluent quality, it is important to establish an effective source control program that includes a municipal wastewater ordinance and a public education program, as to prevent access to the sewer system of undesirable substances, either for the integrity of the sewer system, the treatment process or the reclamation project.

An essential requirement of a reclamation project is the need to ensure a high reliability of the treatment process and the overall management of the reuse system. Reclaimed water is frequently the only alternative water supply, without the eventual protection that dilution with other water sources may provide. Reuse of reclaimed water frequently implies the possibility of direct contact with persons, animals and plants, which can be affected in their health and development. In these conditions, water reclamation facilities must have a high reliability, which has to be incorporated both during their design and construction, as well as during their operation and maintenance.

Water reclamation is currently considered a process aimed at obtaining a quality product: “repurified water”, “new water”, or just reclaimed water. Production and marketing of this new product must be conducted in a larger framework than that traditionally adopted for water pollution control, and with a mentality different than that normally adopted in wastewater treatment, whose final effluent is normally considered a residue, either liquid or solid. This new way of approaching water reclamation has made planned reuse of reclaimed water an essential component of water resources management.

Reclaimed water is being used for numerous beneficial uses: urban reuse, industrial reuse, agricultural and landscape irrigation, supply to recreational and landscape lakes, environmental rehabilitation and enhancement, and groundwater recharge (Pettygrove and Asano, 1984; Asano et al., 1991). The technical debate on the application and future developments of planned water reuse is currently focused on whether indirect potable reuse should be promoted, or planned water reuse should be restricted to non-potable uses. This technical debate has reached high controversial levels in the United Sates (Okun, 1999a, 1999b; Harris, 1999; DeSean, 1999), with obvious political connotations in many cases, and has indirectly cast an unnecessary shadow over a real fact: the great success reached by reuse of reclaimed water for non potable uses in numerous areas, particularly in states like California and Florida, with the largest and more numerous reclamation and reuse projects in operation.

WATER REUSE CHALLENGES

The gradual implementation of water reclamation systems based on join utilization of conventional treatment processes and others based on synthetic membrane (from microfiltration to reverse osmosis) will greatly contribute to further development of water reclamation and reuse (Mujeriego and Asano, 2000; NWRI, 1999). A key determining factor in promoting wastewater reclamation, recycling and reuse is the continued development of cost-effective treatment systems. While water supply reliability may justify the adoption of advanced treatment systems for industrial reuse, that bring the cost of reclaimed water to equal or higher levels than those of conventional water supplies, other potential beneficial uses may require the least cost reclamation alternatives before they may be considered for implementation.

The impressive cost reductions and performance improvement experienced by advanced treatment process during the last two decades anticipates a most promising future for expanding their application. With a development progress driven by the cost margins of the industrial sector, numerous advanced treatment processes are expected to be cost-effective for application in other potential beneficial uses of reclaimed water, such as urban use, and groundwater recharge.

Establishing the cost of reclaimed water is a determining factor of the feasibility and success of any water reclamation and reuse project (Asano and Mills, 1990). Defining the cost of reclaimed water is a complex process, mainly because proving reclaimed water is usually more expensive (dual distribution system) than expanding the existing drinking water distribution system, and also because reclaimed water quality is lower than drinking water quality. However, the long-term benefits of reusing reclaimed water have resulted in water reuse being promoted by many drinking water services. Recent evaluations of price rates applied to reclaimed water (Cuthbert y Hajnosz, 1999) indicate the need to adopt a larger economical and financial framework than that traditionally applied, as to include the abilities of the water reclamation system: 1) to cover its own expenses, 2) to prevent higher costs incurred by new water supply projects, 3) to provide a reasonable contribution of the total cost of the system once it reaches its design capacity.

SUMMARY AND CONCLUSIONS

Planned water reuse is currently considered an essential component of water resources management, particularly in coastal and semi arid zones, where it may have a significant contribution in augmenting water resources, both for direct non potable reuse and for artificial recharge of groundwater. Water reclamation is considered a process for obtaining a quality product. The production and marketing of this product must be conducted in a framework larger than the traditionally adopted for water pollution control, and with a new mentality in planning, design, operation and maintenance of water reclamation processes, substantially different from that adopted in wastewater treatment and disposal.

The technical debated on the future of planned water reuse is currently focused on whether it is appropriate to promote indirect potable reuse, or it is more adequate to restrict water reuse to non-potable uses. Among the technological advances that will contribute to further development of water reclamation and reuse there is the join use of conventional reclamation processes and new synthetic membrane processes, ranging from microfiltration to reverse osmosis. Water reclamation and reuse does depend not exclusively on technological factors. The existence of a solid legal and regulatory framework, and a clear political will to promote water reclamation and reuse, are critical factor for its future development.

The economical and financial analyses of a water reclamation and reuse project must be considered in a larger framework than that normally considered for water pollution control. Reclaimed water cost should be established considering its potential: to cover its own costs, to prevent higher costs associated to developing new drinking water sources, and to contribute to the overall cost of the project once it reaches full capacity. Demonstration projects for water reclamation and reuse clearly contribute to the development and acceptance of these technologies, offer new job openings and considerable prestige to the area, and provide a competitive edge in water management in semi arid areas.

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RECYCLING OF TREATED WASTEWATER FOR AGRICULTURAL AND LANDSCAPE IRRIGATION – TREATMENT OPTIONS AND CHALLENGES

Gideon Oron*

** Ben-Gurion University, Environmental Water Resources Center, The Institute for Desert Research, Kiryat Sde-Boker, Israel 84990. Also at the Department of Industrial Engineering and Management, Ben-Gurion University, Beer-Sheva, Israel and The Water Research Institute, Technion, Haifa, Israel. E-Mai :l <gidi@bgumail.bgu.ac.il>.*

The growing demand for water and increasing environmental awareness recalls for intensive efforts towards improving the treatment and disposal of the reclaimed wastewater. Water shortage problems can be solved by adequate reuse of treated domestic wastewater. The reuse of effluent, primarily for irrigation has a series of advantages, which turn it into a valuable source.

Treated wastewater reclamation serves as solution for closing the gap between water supply and demand. The nutrients contained in the effluent replace artificial fertilizers requirements in irrigated areas, thus can increase productivity. The sludge generated during the wastewater treatment processes can as well be reused as a soil amendment. The sludge can as well be recycled as an alternative energy source by incineration processes. There are also attempts to use the sludge as a source for building material by using it for bricks construction.

Sludge is obtained in most treatment processes. Most of the carbon contained in the raw wastewater can be removed under anaerobic processes, generating biogas as alternative energy source. The sludge after the carbon removal has an elevated fertility value, due to the increased content of nitrogen hence, can be used as an improved fertilizer.

Aquaculture systems consist of combination of plants growing in the water body, living organisms (animals) and wastewater treatment principles. Aquaculture methods combine simple and low treatment techniques and natural processes taking place in nature. Links of the food chain are combined in the treatment process to yield simultaneously several by-products and thus improving the overall economic of the system. The main two by products are effluent for reuse and biomass for animal feed or energy generation. The main drawback of aquaculture systems is the high land requirements, the dependence of treatment on external uncontrolled conditions (environment) and the potential of loosing water due to evaporation. According to the conditions and constructed treatment systems, different species of plants are used.

Integrative research projects for optimal wastewater disposal and reuse with minimal environmental and health risks and elevated agricultural productivity are in progress. Secondary domestic wastewater can be disposed safely under conventional onsurface Drip Irrigation (DI) and advanced Subsurface Drip Irrigation (SDI) systems. Water and fertilizers accessibility supplied under SDI is relatively high in comparison with DI due to close location of the point water source to the main root zone. The soil under SDI performs as a complementary treatment biofilter, an extra stage in the conventional process of the domestic wastewater treatment.

Outdoor experiments are in progress in various commercial fields with different effluent qualities, treatment methods and crops. The results indicate that improved agricultural yields are obtained under SDI, probably due to several agronomic advantages such as high nutrient availability and reduced salinity effects near the water irrigation point source. In addition, the health and environmental risks are diminished due to minimal contact of the disposed effluent with on-surface agro-technology activities. This includes as well no direct contact of the above surface foliage parts of the plants and fruits and the applied effluent. No specific problems of emitters clogging were encountered due to adequate filtering of the effluent at the head control.

To enable optimal reuse, studies towards the examination of the content of pathogens (bacteria, viruses and parasites) in the effluent and the related impact on the soil, plants that human or animal consumer, are in progress. The content of nutrients and the additional constituents in the effluent might have adverse effects on agricultural productivity, both on a short and a long-range time scale. The long range effects are primarily related to dissolved solids accumulation in the soil, plants and the ground water

Consequently, research has to focus simultaneously on several areas related to increase the available water potential. These include improved treatment of domestic, industrial and agricultural wastes, obtaining effluent quality with minimal health and environmental risks. The advanced treatment methods should be based on combined biological, chemical and mechanical processes, including methods of membrane technology and disinfection processes with minimal by-products. The residual by product generated during disinfection might be unsafe for consumption by the human and animal. Also should be examined technical methods for improved disposal and reuse of the effluent. The later include primarily drip irrigation for agriculture.

RECYCLING OF TREATED WASTEWATER FOR INDUSTRIAL REUSE

L. Bonomo*

** D.I.I.A.R. - Environmental Section - Politecnico di Milano, Piazza Leonardo da Vinci, 32 - 20133 Milano, Italy*

INDUSTRIAL WATER WITHDRAWALS

The extent of the industrial withdrawals with respect to the global water supply is essentially depending on the hydrologic regime and on the country level of industrialisation and income. According to the water resources data published by the World Bank, the industrial sector is the second largest water consumer with an average of 23% of the total usage, increasing to 47% in high income countries. Nevertheless different countries offer consistently different situations. Table 1 gives some examples of the importance of the industrial sector on the global water consumption. This high variability is also the outcome of a non homogeneous classification of the uses with the frequent inclusion of the energetic sector within the industrial portion.

Concerning the Italian situation, industry requires around the 19% of the overall water withdrawal. Inland thermo-electric plants respond for another 14%. All the sea water usage of coastal thermo-electric plants as well as the hydro-electric uses without an effective water consumption, are not included in such figures.

After a long period of intense exploitation, at present the industrial water consumption is significantly decreasing in the majority of developed countries. This is primarily a consequence of the changing occurred in the industrial structure. Some of the highest water consuming productions (steel, rubber, chemical, metallurgy, petrol-chemical, refinery) have stopped or moved away. Sometimes they have converted their activities from primary to manufacturing productions, generally characterised by lower water consumption and pollution loads.

Table 1. Incidence of the industrial sector on the global water consumption in different countries.

Country	Industrial withdrawals
Argentina	18 %
China	7 %
Denmark	27 %
Portugal	37 %
Romania	33 %
Sweden	55 %

Table 2. Annual water withdrawals in Italy (km^3/year)

Uses	Annual consumption $km^3\ year^{-1}$	Percentage %
Urban	7.94	18.9 %
Irrigation	20.14	48.0 %
Industrial	7.97	19.0 %
Energy	5.92	14.1 %
Total fresh water	41.98	100 %
Sea water (cooling)	17.00	

Moreover the increasing trend in wastewater treatment costs due to the widespread tightening of the water quality standards for environmental protection has led to the adoption of cleaner or advanced technologies in order to minimise the water usage. The Italian case has been a clear example of this evolution after the Water Policy Act was issued in 1976. In the following ten years remarkable efforts were made to reduce the industrial water consumption as shown in Table 3. These data come from investigations performed by IRSA-CNR, the Italian Water Research Institute, in 1972 (before the Water Policy Act was issued) and in 1986, 10 years later. This trend is still going on, being cleaner technologies and strategies for water saving still not thoroughly applied by industry.
Table 3 shows the water reduction per worker, but lacks of analogous estimates referred to the unit product. Therefore greater reductions should be predicted as the industrial productivity has remarkably increased during the last 15 years.
In temperate regions the increase of wastewater reuse, in terms of direct recycling or in terms of municipal wastewater application, rarely depends on real availability problems of the water resource. More frequently the convenience of the reuse strategy derives from a cost benefit evaluation, since costs for fresh water supply (including wastewater treatment) and costs for water reclamation are often comparable. The widespread tightening of the effluent discharge permit limits in developed countries has gradually determined a diffuse need of tertiary treatment steps such as:

- biological removal of nutrients (nitrification/denitrification);
- final filtration for suspended solid and phosphorus removal;
- chemical oxidation or activated carbon filtration for colour and detergents control;
- enhanced disinfection in order to respect higher microbiological standards.

INDUSTRIAL WATER RECLAMATION

Industry requires water for processing, steam generation, product washing, air conditioning, plant and equipment washing, transport of materials, cooling systems and sanitation. At present, cooling water is the industrial application that consumes most wastewater. It should be stressed that water quality requirements for industrial reuse are necessarily specific, depending strongly on the type of process and on the kind of reclamation strategy. Different water requirements correspond to different uses. Lower quality water may often be employed.

Table 3. Industrial water minimisation occurred in Italy, during the 1976-1986 period, after the Water Policy Act was issued. Values are referred to manpower.

Industry	Minimisation
Grain Mills	- 28 %
Paper	- 54 %
Dairy-farming	- 40 %
Sugar	- 56 %
Leather	- 24 %
Textile	+ 15 %
Metallurgic	- 50 %
Mechanic	- 23 %
Chemical	- 7 %
Rubber	- 80 %
Synthetic fibres	- 80 %

Water requirements for industrial reuse are quite different from agricultural or urban non potable reuse. Microbiological quality is not the main concern for most of the industrial applications albeit when municipal wastewater are employed. Additional health protection measures can be adopted to minimise worker exposure to toxic volatile organic compounds or pathogens. Frequently quality concerns include scaling, fouling, corrosion, foaming, biological growth, workers safety.

The reclaimed water use depends on several factors:

- Availability and cost of alternative water sources
- Costs of wastewater treatments required to respect regulations on water quality standards.
- Water quality and quantity requirements of the specific industrial processes.
- Possible recovery of heat, process chemicals or by-products (e.g. cellulose fibres in paper industry, sizing agents in textiles, metallic ions in plating industry, chromium salts in tanneries).

Water reclamation alternatives include:

a) direct reuse of non-contaminated water (e.g. cooling water to general factory use);
b) closed loop treatment and recycle of wastewater from a particular source for direct reuse in the process. This is often accompanied by recovery of process chemicals, by-products and heat energy;
c) cascading of water used on a high quality process to another process requiring lower quality water (e.g. final rinses to first rinse operation). In many application such cascade reuse may require only minimal intermediate treatments, and the lowest quality of water is disposed of as unusable;
d) treatment and reuse of end-of-pipe factory mixed effluent;
e) reuse of municipal wastewater for an industrial process. It is normally meant to satisfy the basic water quality requirements for general industrial applications, leaving any further polishing treatment to the specific user. However, this option is marginal, since, on average it accounts for less than 6-15% of the overall reclaimed wastewater used in the industrial sector.

Industrial reuse can require a complex array of integrated processes to ensure a safe water supply at an affordable cost. This typically implies coupling the most effective wastewater and water treatment technologies in complementary treatment trains.

PINCH ANALYSIS

Recently new cost/benefit evaluation strategies have been developed in order to assess the best recycle/reuse alternatives that enable to optimise freshwater usage and the level of water reuse. Most of these systematic approaches include elements of *Pinch analysis*. "*Pinch*" in this context means "*bottleneck*". Pinch analysis extends the basic concepts of heat recovery to freshwater and wastewater minimisation adopting the model of a thermal mass-transfer unit. Contaminant levels and flow rate *in* and *out* of different process units are the equivalent of temperature in a thermal mass/transfer balance.
Pinch analysis helps to identify potential water use reduction and wastewater minimisation. Basically it considers a plant as a whole and provides indication on the critical steps among different process units. On the basis of this critical point (the bottleneck) it's easier to detect which water streams have to be recycled and/or which internal wastewater treatments have to be provided to optimise the water usage. In other words this indication allows to design the optimal scheme for the process units.
Each operation in a process can be analysed as a single unit characterised by certain ratios between input and output contaminant concentrations. The mass/transfer balance for each operational unit is described with a graph (Figure 1) reporting contaminant concentration versus the mass transferred.

The highest permissible input/output concentrations indicate the *operational limit profile*. These inlet and outlet concentrations may be fixed by a number of possible factors such as solubility, fouling of equipment, minimum flow rate requirements to avoid settling of precipitation of material, etc. Any other possible operational profile would lie below the limit profile.

To represent the overall water consumption, a cumulative curve (Figure 2) has to be built using the limit profiles of each operation unit of the process. The cumulative curve, combined with the limit water supply requirements of the processes (the water requested to guarantee the inlet limit concentrations for each operational unit), allows to identify the bottleneck (*the pinch*) of the process.

Figure 1 – Mass/transfer balance for a single operational unit and a single contaminant. The bold arrow indicates the *operational limit profile*.

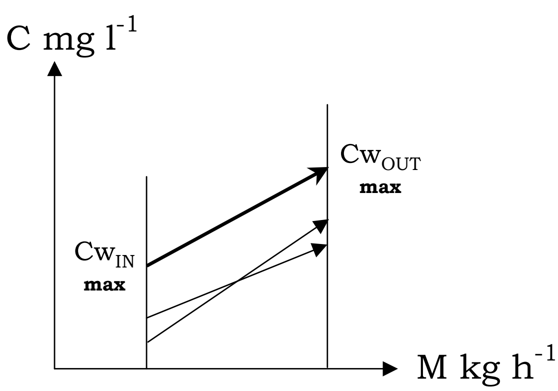
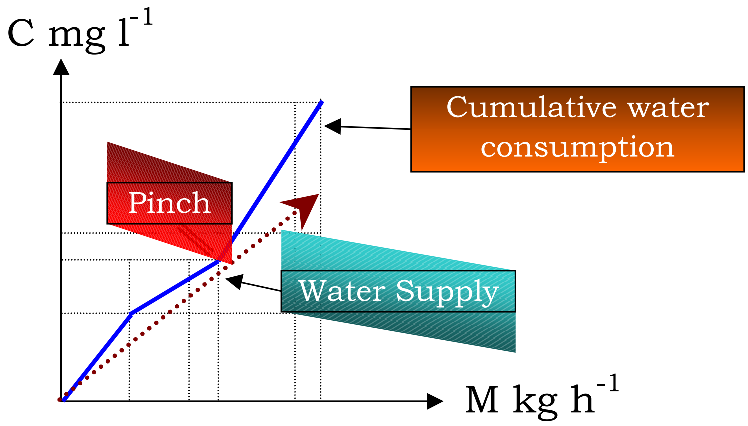


Figure 2 – Cumulative water consumption curve. The arrow is minimum water supply required to guarantee the limit concentrations for each operational unit.



On the basis of the knowledge of the *pinch,* an optimised scheme of the process units can be achieved. An internal recycling placed in an appropriate position would be able to effectively reduce the *pinch* concentration and therefore the overall fresh-water consumption.
Iterative software, specifically developed to return the best operational configuration for a certain set of constraints (maximum inlet/outlet concentration and/or mass load of contaminant transferred and/or minimum flow requirements), can be applied to investigate the best scheme solution.

WATER RECLAMATION IN SOME INDUSTRIAL SECTORS

Textile

Textile factories are among the largest industrial consumers of water. Effluents of textile processing plants contain several complex compounds deriving from the major step of sizing, desizing, scouring, dyeing, printing and finishing, and are quite variable because of the frequent changes of batch-type textile processing steps.
Textile wastewater may include many types of recalcitrant and biotoxic chemicals. The variability of these compounds in concentration and discharges makes textile wastewater treatment quite problematic by conventional processes, either physico-chemical or biological.
This difficulty in treating wastewater has gradually forced industry to adopt additional end-of-pipe treatments (GAC/BAC adsorption, oxidation, evaporation and membrane treatments) in order to match the sewage discharge limits.
Wet processes in textiles generally require high quality water. Therefore any recycling strategy implies high performance treatments. At present, direct recycling experiences are limited to single wastewater streams: mostly water from final washing steps reused in first rinsing baths. Salinity increase, due to chemicals used in the processes or for the regeneration of ion-exchange resins, is generally the limiting factor for recycling rates.
Reclaimed water is normally used for specific production steps, not particularly exigent in terms of water quality, such as cooling of dyeing machines, first rinsing and rinsing for dark dyeing. Fresh water is generally essential in the boiler house, for personnel consumption and sanitation, for dyeing and for the last rinsing steps. Such limitations in reclaimed water employment may be overcame with membrane treatments that now are less expensive than few years ago. Promising results, also

in terms of economic feasibility, have been obtained at a demonstrative scale by using low-pressure reverse osmosis membranes.
As polishing schemes for reuse, several combination of treatments are usually adopted (sand, (bio-) activated carbon filtration, oxidative and membrane treatments). Oxidative treatments are very effective towards the degradation of dyes whereas membrane treatments may allow the recovery of chemicals. At present, cases of textile industries where some water is ordinarily recycled or where in-plant measures have been introduced to recover chemicals (primarily sizing agents, mercerising agents and indigo) are still quite rare.
Reuse strategies have been applied to centralised municipal wastewater treatment plants. The Prato Industrial Aqueduct located in Central Italy, is the most significant Italian example of textile wastewater reuse. Prato is a town, near Florence, of more than 170,000 inhabitants where 3,500 small and medium size textile industries employ a total amount of about 55,000 workers, including artisan activities.
The Prato centralised wastewater treatment plant (MWWTP) treats mixed urban and textile effluents with a conventional chemical-physical and biological process and has a tertiary refinement step including clarification-flocculation and ozonation (Figure 3). From the MWWTP plant, a fraction of treated wastewater (about 2,000,000 m^3 year $^{-1}$) is sent to a polishing treatment plant made by a contact filtration and a biological activated carbon filter (BAC). The reclaimed water, diluted 1:1 with surface water from river Bisenzio, is employed for industrial uses. The mixing is necessary to lower the operating costs and to reduce the salinity.
Figure 4 shows the trend of the industrial water consumption and the increasing relevance of the reclamation water supply of the Industrial Aqueduct in Prato.

Figure 3 - Scheme of the Prato MWWTP and of the industrial refining treatment plant.

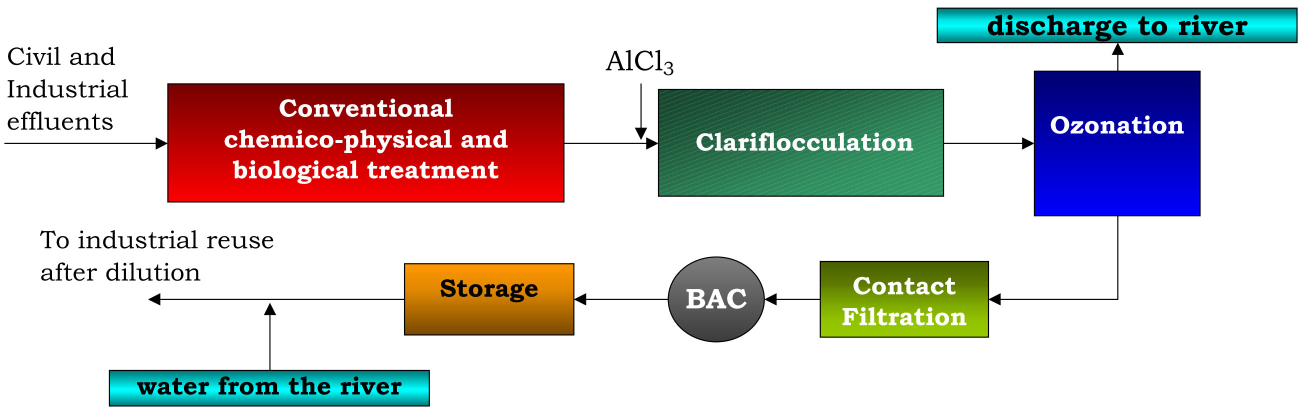
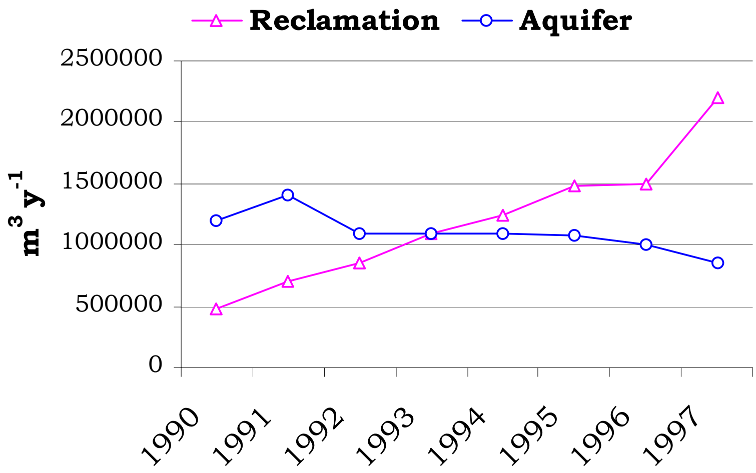


Figure 4 – Trend of the Industrial water consumption in the Prato area.



Similar experiences have been carried out in the Como area where a municipal WWT plant (Fino Mornasco) treats wastewater composed for the 60 % of textile effluents. The full-scale plant is composed by conventional secondary treatments (including nitrogen control) followed by sand filtration and ozonation. A subsequent demonstrative scale GAC adsorption phase has produced water of suitable quality for many textile applications (COD in the order of 40 mg l^{-1} and colour lower than optical detection limit), requiring however frequent regeneration (once every 3-4 months).

Paper industry

Water usage in paper industry has been tremendously changing during the past two decades. Nowadays effluent recycle is usual both into the pulper and into the white water circuit. In the case of white water, high removals of suspended solids are needed and generally secured by dissolved air flotation followed by filtration step.

These treatments allow remarkable water savings and significant by-products recovery (especially of fibrous materials previously discharged to receptors or disposed with the sludge). In Italy recycled paper mills effluents have shifted from 30-40 to 4-5 m^3 ton^{-1} of product. Several paper and board mills have managed to run a closed loop treatment in order to avoid wastewater discharge and to maintain high water temperature. Anyway the consequent accumulation of dissolved and colloidal material, together with the occurrence of bacterial growth, have often affected the paper making process (scaling, corrosion) and caused detrimental effects on the final quality of the product.

These process transformations have considerably modified the final effluent characteristics. COD values of some g l^{-1} and temperature higher than 35°C are now frequent. In the end-of-pipe wastewater treatment scheme, an anaerobic pre-treatment is often included. UASB (*upflow anaerobic sludge blanket*) reactors placed prior to aerobic conventional treatments are employed in several plants.

Tanning Industry

In the tanning industry, the transformation of the raw skin into leather is achieved by chemical and mechanical operations. Water and chemicals are consumed in huge amounts in many steps of the process, with significant pollution effects due to organic substances removed from the skin and to the chemicals not completely reacted. Trivalent chromium (about 30%), if not recovered, is discharged into wastewater, giving place to serious problems for biological wastewater treatments and for final sludge disposal. The recycling option, usually limited to chromium recovery, can be combined to a partial recovery of water.

Chromium recovery from spent tanning baths is frequently operated by conventional precipitation-dissolution methods. The spent float is precipitated with sodium carbonate and filtered through a filter press. The chromium hydroxide panels are dissolved in sulphuric acid and transformed into a reusable tanning solution of poor quality, due to the presence of organic compounds, metals and other impurities.

Promising tests with membrane processes (nanofiltration and reverse osmosis) have been carried out, to improve the recovery of chromium, water and chemicals from the filter-press effluent. The resulting permeate, with low salt content and a chromium concentration below the detectable level, is suitable for reuse, for instance for the filter-press washing.

Waste processing plants

Recycling for internal uses is quite common in wastewater treatment plants. Back-washing of tertiary filters, press filters washing, general cleaning activities, wet scrubbers of exhausted air emissions are the main possible applications. Coupling with solid waste disposal plants can offer further opportunities. For example, treated effluents can be used as cooling streams in steam condensers at waste-to-energy plants.

Tertiary nitrification can be operated as a separate step as one of effluents finishing treatments. Since nitrification rate is heavily depending on temperature, winter performance can be significantly improved if waste heat from condensers at waste-to–energy plant can be used to increase effluent temperature

This is a case recently applied at Bergamo MWWTP (about 200.000 P.E.) where a 10 to 12 °C increase has been obtained in winter months, leading to an important reduction in the reactor volume.

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RECYCLING OF TREATED WASTEWATER FOR INDIRECT POTABLE AND URBAN REUSE – TREATMENT OPTIONS AND CHALLENGES

Takashi Asano

Department of Civil and Environmental Engineering, University of California at Davis, Davis, CA 95616-2311, U.S.A.

INTRODUCTION

For the last quarter century, a repeated thesis in responsible engineering in the environmental engineering fields has been that advanced treatment of municipal wastewater provides a treated effluent of such high quality that it should not be wasted but put to beneficial use. This conviction in ensuring efficient use of water and reliability of water supply, coupled with the vexing problem of water shortage and environmental pollution, provides a realistic framework for considering reclaimed municipal wastewater as a water resource in many parts of the world. The purpose of this presentation is to delineate current opportunities and challenges facing indirect potable and urban reuse of treated municipal wastewater in industrial countries.

RECLAIMED WATER QUALITY.

Fig. 1 shows, conceptually, the quality changes during municipal use of water in a time sequence. Through the process of water treatment, a drinking water is produced which has an elevated water quality meeting applicable standards for drinking water. The municipal and industrial uses degrade water quality, and the quality changes necessary to upgrade the wastewater then become a matter of concern of wastewater treatment.

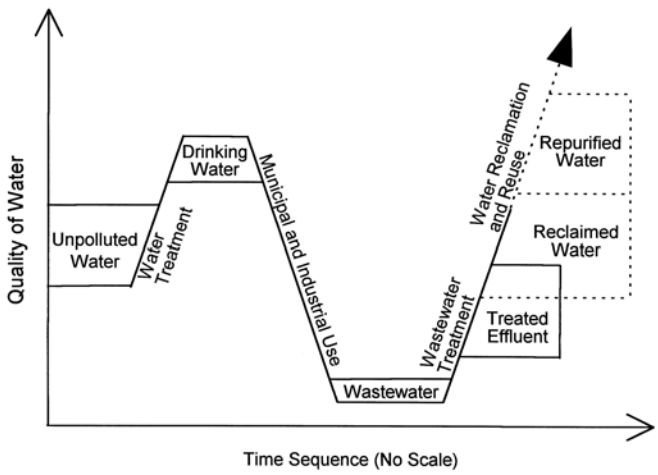

Figure 1. Water quality changes during municipal uses of water in a time sequence

In the actual case, the treatment is carried out to the point required by regulatory agencies for protection of other beneficial uses such as aquatic environment. The dashed line in Fig. 1 represents an increase in treated wastewater quality as necessitated by water reuse. Ultimately as the quality of treated wastewater approaches that of unpolluted natural water, the concept of wastewater reclamation, recycling and reuse is generated. Further advanced wastewater reclamation technologies, such as carbon adsorption, advanced oxidation, microfiltration, and reverse osmosis, will generate much higher quality water than conventional drinking water, and it is termed *repurified water* in this diagram. Today, technically proven wastewater reclamation or purification processes exist to provide water of almost any quality desired.

URBAN WATER REUSE.

Fig. 2 shows comparison of water reuse in California and Japan. The majority of wastewater reuse in most countries is for irrigation; for example, 68 percent of the total water reuse in California (*vs*. approximately 16 percent in Japan) is for agricultural and landscape irrigation. Water reuse in Japan is, however, decisively orientated towards urban reuse applications.

California: $434 \times 10^6 m^3$ (1999 data) Japan: 206×10^6 m^3 (1997 data)

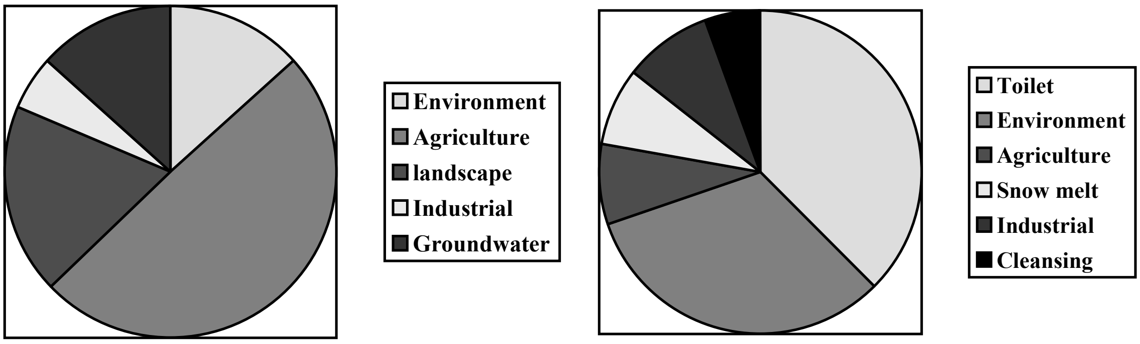

Figure 2. Comparison of water reuse in California and Japan

Water reuse for toilet flushing in large commercial buildings and apartment complexes has been the hallmark of Japan's water reuse with high tech wastewater treatment. The water quality criteria for this use, however, are equal to or less than 1,000 /100 mL fecal coliforms, compared to California's 2.2/100 mL total coliforms for similar applications. There is an assumption that no cross-connection would occur; thus, no annual cross-connection inspections are required after the initial inspection when constructed. There is a discussion among government agencies in Japan that more comprehensive reclaimed water quality criteria be adopted in the near future to protect public health, and to enforce cross-connection inspection in commercial buildings where reclaimed water is used for toilet flushing and other in-building applications.

Water reuse in Japan is not cheap. Although the yardstick price for reclaimed water of about 80 percent of the drinking water price is generally applicable, reported production cost for the reclaimed water in the Fukuoka City is $\$2.0/m^3$ compared to that of drinking water of $\$1.9/m^3$. The consumer price of reclaimed water averaged $\$3.0/m^3$ compared to the drinking water price of $\$3.7/m^3$. Even with a small margin for the reclaimed water, Fukuoka City has been able to produce a slight profit for its wastewater reclamation and reuse systems. In some cases, parks and recreation department considers reclaimed water as "new water" for newly created parks and playgrounds, golf courses as well as for "water amenities" in the urban redevelopment.

POTABLE WATER REUSE.

The only well-studied case of planned direct potable reuse system in operation is in Windhoek, Namibia. For nearly 30 years, this facility has been used intermittently to forestall water emergencies during drought conditions. The current treatment process sequences involve primary, secondary treatment, and maturation ponds at the Gammans wastewater treatment plant. The secondary effluent is then directed to the Goreangab water reclamation plant, which includes alum addition, dissolved air flotation, chlorination, and lime addition, followed by settling, sand filtration, chlorination, carbon filtration, and final chlorination. The final effluent is then blended with other dinking water sources before distribution (Harhoff and van der Merwe, 1996).

Much of the objection to planned potable reuse of wastewater in the United States arises from a concern whether drinking water standards are adequate to ensure the safety of all waters "regardless of source." Some argue that drinking water standards apply only to – and were designed only for – waters derived from relatively pristine source. Although this argument has a long-standing basis in normal sanitation practice, it is becoming more difficult to determine what is the best available water source (National Research Council, 1998).

While direct potable reuse is not practiced in the United States, planned indirect potable reuse is implemented to augment several drinking water systems, and several pilot facilities have been constructed to evaluate the potential for direct and indirect potable reuse. Several examples are given below (Asano, 1998; National Research Council, 1998):

1. The Denver Water Department's Direct Potable Water Reuse Demonstration Project, 1979-1990
2. The Potomac Estuary Experimental Water Treatment Plant, 1980-1983
3. The County Sanitation Districts of Los Angeles County Ground Water Recharge Projects, 1962-present
4. The Orange County Water District, California, Water Factory 21, 1972-present
5. The Fred Hervey Water Reclamation Plant, El Paso, Texas, Groundwater Recharge, 1985-present
6. The City of San Diego's Total Resource Recovery Project, 1984-1999
7. The City of Tampa, Florida, Water Resources Recovery Project, 1993

Despite technological advances and high quality of treated effluents (c.f., Figure 1), public reactions to direct potable reuse, and even indirect potable water reuse, have not been encouraging. The following are some of the newspaper clippings related to indirect potable water reuse:

- No such thing as 'New' water – all is recycled to some extent (The Sacramento Bee, April 21, 2000)
- No takers on water purifying – The Dublin Services District is stuck with a $20 million toilet-to-tap treatment system that resident oppose (The Sunday Times, October 18, 1998)
- A proposal to 'mix purified sewage with drinking water supplies' was put on March 8, 2000 ballot as Measure J, which resulted in 76 percent against the project (San Francisco Chronicle, February 26, 2000)
- Los Angeles residents aren't lapping up toilet-to-tap water plan (The Sacramento Bee, April 20, 2000)
- Toilet-to-tap idea gets the big flush, this time for good – dead, killed, buried, gone with no chance of coming back to life – ever, forget it (San Diego Union, Tribune, May 19, 1999)

As seen in these media reporting on the indirect potable water reuse plans in the United States, there has been a strong opposition to "planned" potable water reuse: "yuck factor" in "toilet-to-tap" analogy, “rich man’s sewage to poor people’s drinking water;” thus, one could be “easily demagogued.” **The project could be the safest thing in the world, but there is a much bigger issue politically and socially.** Observing recent incidences in California, the “maximum” available technologies should be used when water reuse applications involve indirect potable reuse including micro-filtration, reverse osmosis, and extensive disinfection. As noted above, even these “maximum” technologies are not good enough in the public’s mind if potable reuse is perceived. Enormous price must be paid for the water “once contaminated” but “repurified” for planned potable purpose. Our opportunities and challenges will continue for the future.

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PUBLIC HEALTH ASPECTS IN WASTEWATER RECLAMATION, RECYCLING AND REUSE - TREATMENT OPTIONS AND CHALLENGES

J. Bontoux*

Université Montpellier, Montpellier, France

INTRODUCTION

Today, in industrialised countries like the European countries, the technical problems do not limit the development of wastewater reuse for irrigation or sludge valorisation for land spreading; they are the reserves for the population who is concerned about its health problems.

According to the WHO, the definition of health is a " state of total well being, considering physical, mental and social points of view " and it became the first value in our societies.

However, the relation between health effects and low doses of contaminants (it is the field which is approached here since one considers in principle the products that are purified, treated and controlled in term of quality and use) is not accessible by measurement. Only by modelling, with all the assumptions that accompany it, allow an approach to it.

It is therefore necessary to manage the incertitude, to encircle it and especially appreciate the acceptation degree of the risk by the concerned population. The decisions depend much more on the perception of the risk than of its objective evaluation.

In the current context we are considering to make the value limit increasingly severe. This causes not only technical but economic problems, which can also lead to the transfer of the problems of pollution, in particular towards the atmosphere without any benefit for the total protection of the environment.

The principle of precaution can be the best or worst thing.

HOW TO DETERMINE THE INCERTAINTY?

It is known that the use of water or of rough sludge causes bacterial, viral or especially parasitic infections among humans and animals.

Certain data exist in the literature; others are more or less voluntarily occulted, particularly in Southern countries, by fear of incidences (often irrational) on the tourist migrations or export of fruit and vegetables.

On the other hand, purified water or treated sludge used in more or less strict observance of a regulation does not seem to have had any sanitary incidence. Generalisation appears possible in spite of the differences noted between the various regulations.

One should however not conclude that it is enough to be satisfied by meeting the standards of the minimal laws. Certain dangers remain:

- Is it necessary to control the Légionella's in the aerosols formed at the time of the irrigation by water sprinkling worn treated?
-" Is hygiénisation needed " all sludge because certain eggs of helminths survive more of one year in the grounds?

In the biological field a question can also arise with acuity in the future. To weigh the re-use of wastewater and the derived product benefaction, we should request the possible presence of transmissible non-conventional agents (ATNC) of the type.

<u>Up to what point can the rejections in source of squarings and even slaughterhouses bring ATNC?</u>

Measures of precaution are already taken on this subject. But the highlighting of the ATNC is currently impossible, the relations amount-effects are unknown; it is the same for the duration of survival in the environment; and the techniques of inactivation are at the very least to specify.

In the field of the chemical contamination it is usual to evoke the traces of metal elements; many data are available and even if unknown factors remain about them, in particular in terms of speciation in the grounds and coefficients of transfer between the various links of the ecosystems, they do not pose effective problems of health if a supervision minimum is carried out.

The question of the organic traces is certainly more difficult to manage. The data on sludge and soils are restricted, and even more on wastewater.

Some regulations exist to limit the contents in sludge; they are seldom based on objective scientific data; they concern primarily more or less adequate applications of the principle of precaution.

The directive n∞ 86/278 applicable to sludge is being revised in Brussels; the preliminary works evoke control, in addition to PCB and HAP of AOX, PCDF, PCDD, and nonylphénols... It is possible that the final text will be less demanding, but the questions are formulated. One is completely in the general uncertainty of low dose, where rationality has great difficulty to be expressed. The toxicology of the traces is a future science.
Fortunately risk assessment methodology allows of useful comparative reflections today.

TO APPRECIATE THE ACCEPTATION DEGREE OF THE RISK

The acceptation of a risk depends on many parameters related to the balance of a Society. It is necessary to develop research in order to analyse it. It is in the field of sociology and not of biological or medical physicochemical sciences. There are however interfaces where the limits of the disciplines are difficult to trace. The epidemiology is one of them.

<u>Indeed, in the appreciation of the contamination of the environment, the epidemiology is currently on the field a tool with two uses:</u>

- A scientific use contributing to the appreciation of a risk for a particular population under conditions of given expositions;
- A communication use employed to respond to the anxiety of the population, even if all the requirements to ensure the rigour of the investigation are not combined.

The difference between these two uses can be very clear; it is not always in fact.

TREATMENT OPTIONS AND CHALLENGES

The process options go for the wastewater reused from a simple lagunage to a sophisticated chain of treatment, with the membrane techniques; for sludge they go from a traditional stabilisation to a thorough hygienisation. The treatment of biological contamination is relatively overpowered, except for the ATNC; it is not the same for the organic contamination where practically only the quality control of the water before the admission in the networks collecting wastewaters is efficient. It is the definition of the acceptable limit values that decides the choice of the processing.

The challenge is only partly at the technological level, it is elsewhere.

Two requirements are needed for the development of the re-use of wastewater and the valorisation of sludge

- To impose to all the implied actors a discipline of management because the public health hazards can be significant if the uses are done without control.
- To erase the negative image of treated waste water and sludge in the public opinion by comparing the medical risks with the other risks (pesticides, animal dejections, degraded quality of " natural " water of the courses of water used in irrigation, pollution air etc..)

To accompany these two steps the development of the epidemiology, which is today insufficient, is essential.

The epidemiologic studies are difficult and expensive if we want she have the " power " necessary. They must be multiplied and made comparative.

<u>The interpretation of the epidemiologic results must bring together the specialists in public health, the communication sector and the decision-makers.</u>

Many efforts remain if we wants that the valorisation of waste water and products derived take a broad rise in Europe.

CHALLENGES IN THE REUSE OF RESOURCES IN WASTEWATER SLUDGE

P. Mattews*

*Pelican Portifolio, Slepey House, Honey Hill, Fenstanton, Cambs.PE18 9JP, UK

INTRODUCTION

Human waste has always been considered a resource for agriculture, but it has always had an uncertain reputation. This has been due to the smells and perceived risks associated with the product. The challenges now lie in overcoming prejudice, which is worsening as individuals become even more remote from the realities of human waste management and food production. City dwellers have different attitudes to country dwellers; some of the most vociferous critics are city workers who live in the country and commute into cities. However, the wastewater industry must accept this as the working reality and respond to it. It is helpful to examine the history of the practice. So, where were our societies a thousand years ago in terms of biosolids management? It is fascinating because by our current understanding the issue did not arise until the last hundred years and probably the last fifty years.

Not much progress was made in rural European societies on the management of faecal wastes beyond the ideas of middens or pit latrines and the products of these were often put on agricultural land. Similarly explorers and early settlements in the American continent either "lost" their wastes in the environment or had middens .

However, the stresses caused by the development of denser societies led to the extension of the water flushed system. This idea extends back thousands of years, but was reserved for the rich few and it left dreadfully insanitary conditions in the towns . The extension of sewerage systems helped solve the sanitation problems in the streets , but exacerbated the problems in the rivers , where the sewers discharged. So, water became even more contaminated . By the end of the 19th century the first sewage treatment works were being provided . In some cases this was as simple as a "sewage farm" in which the natural capacity of soil was used to treat wastes. The term still lingers on in some places and some soils became heavily contaminated with metals present in the sewage. Crops were grown and animals were raised and there were cases of diseases in those animals.

The early days of sewage treatment in the 20th century produced a variety of sludges , which were disposed where-ever convenient, be it land or sea, and that was often nearby farmland when it was used by the same practices as those employed for animal manures. Incineration came later, but landfill was popular in many places.

After the Second World War, there was an awakening to the notion that proper and full sewage treatment and good management of sludge was crucial and 'higher tech' solutions started to emerge. The 1960's and 1970's were the" watershed" in most places [or should we say the 'waste-water shed '] in our thinking. .So much of the collated evidence on sludge management arose from that period onwards, albeit, in some cases, drawing on information gathered previously, particularly form land and sea sites, which had been used for a long time.

From this time onwards 'the environment' has been a major social issue and in later years food quality has joined it. So there has been an awakening of public and political interest in the topic of sludge disposal, which had been ignored in the past - perhaps a case of "out of sight - out of mind". So practices which are intrinsically safe, by virtue of historical and scientific evidence, are no longer acceptable. Examples include the use of untreated biosolids on cereal growing arable land and the dispersal of sludge at sea. All the issues surrounding marketing, such as perception, the use of correct but evocative language ,and communication skills are now amongst the drivers in waste-water solids management.

This is the contemporary reality. Water utility managers have to learn to co-exist and cope with unreasonable criticism. We all have a ' faecal aversion barrier'. Faecal matter itself has a malodour to provide a psychosomatic warning that the origin of the odour is a micro-biological hazard. We are all taught the elements of public health training in childhood and this pre-conditions us to the hazards of faecal matter. It is only when societies become stressed and impoverished that these hazards are tolerated .

So , we are poised at the end of the Millennium [31 December 2001] with marine dispersal banned, incinerators not popular, landfill not popular and diminishing in opportunity and cost effectiveness, and agricultural use under intense scrutiny. There is also concern about food quality and biosolids use is getting dragged in without there being any evidence that biosolids fertiliser has caused problems. At the time of writing, the European ' beef wars ' are a good example. There is also concern about the rising cost of water utility services to meet all the new demands. These concerns are universal. Exotic alternatives to the conventional options are fascinating to environmental journalists, but difficult to apply due to high cost or limited opportunity. For example, vitrification only works in large conurbations such as Tokyo. So, we are faced with increasing difficulties and the opportunities .

Public acceptance is crucial and communication with and between stakeholders can or break operations. We can work as hard as we like on risk management but an ability to express it can render the work ineffective. The behaviour of organisations and their employees sends signals to the wider community. Dirty vehicles, dirty operations, scruffy employees and malodours are the first hurdles in a sustainable operation. Get these wrong and you will have no need to worry about the other issues because there will be no operation! Of course you will have the much bigger worry of what to do with the sludge as it is piling up in your works!!

So with all the effort going into public acceptance - why are we still having so much trouble? Could it be that even the concept of 'acceptance' is the wrong one; does the word imply 'will not put up opposition' rather than positive support or even desire? There are a number of other paradoxes in our practices. This paper focusses on the issues relating to the use of biosolids in agriculture, but it also recognizes the other beneficial uses of biosolids, particularly in other forms of land use.

SOME PARADOXES TO THINK ABOUT

We may say that we understand the issue of public acceptance and espouse it as the desirable goal but a question may be posed - is it a means to an end of the goal , a necessary and unavoidable goal, of safe and sustainable disposal of waste water sludge - or is it to serve the goal of conserving the planet's resources through re-cycling.

However , the messages we send are confusing and provide material for those seeking to make reputations by criticising wastewater management or who have primitive fears as described earlier. Some examples are given below ;

- We are totally confident that biosolids are safe to use , yet we continue to do research on quality so we give the impression that we do not really know about safety issues . So our critics demand that we should be safe rather than sorry. This is a problem for all prudent research on environmental matters. It must be done , but we need to be careful in explaining what we are doing and why.
- We encourage farmers to use biosolids, within the context of prudent control , yet our research on treatment is to produce as little as possible for economic reasons, but this sends the message that the product is a liability.
- We say that the word "biosolids" is right for wastewater sludge used beneficially as a land fertiliser in accordance with Regulations and that the term 'sludge' should be restricted to other disposal activities and to the material within the wastewater treatment works. So the essence of the concept is beneficial use. Does the public really accept the extension of the term to include incineration? Whatever we say about energy recovery the very word 'incinerate' means to burn up and sludge is burned alongside other unwanted wastes from society. Is it just wood and coal which are burned just for their innate energy ?
- We have invested a great deal of effort in the development of a better syntax for sludge , but there-in lies the rub! We refer to waste-water or sewage treatment works, rather than water recovery works.
- The whole grammar and syntax of used water management needs review. This should not create an Orwellian nightmare, in which syntax is used to hide the truth, but be developed in a way which is more accurately descriptive. We cannot deny that language shapes minds and attitudes and we need to remember the holistic perspective rather than getting carried away in our little world. This is fraught with difficulty - some critics already view 'biosolids' as being Orwellian and would prefer to call "a spade a spade" and suspect a cover-up. However, 'water recovery processes' have a better sound to them in the modern context than 'sewage or waste-water treatment' much as 'biosolids used in agriculture 'sounds better and is more accurate than 'sludge dumped on land'. The term "biosolids" is prone to get diluted by a variety of interpretations, so wide-spread agreement on, and absolute discipline in, useage of the word is crucial and often lacking.
- We tell local communities that we are going to clean up the local rivers by removing sewage [or rather, to be more precise , remove the polluting components of sewage], and then we expect to take many of those components back into the community as biosolids.
- We ask farmers to use biosolids , because they are safe, yet we often refuse to offer explicit indemnities or guarantees against changes in legislation.
- We say that safety lies not only in the quality of the product, but the caution and care with which operations are managed - yet quality assurance and environmental management systems , the bed-rock of reproducibility , sustainability and safe practice , have been introduced slowly and reluctantly in some places for fear of the additional powers that this might give the Regulators. What does the public make of that ? We give the impression that we have something to hide.

So why do not we put ourselves in our customers shoes and ask some fundamental questions about our attitudes and communication syntax . This one function which the professional associations can carry out as they are seen to have less vested interest. There is fear by these organisations of deliberately encouraging public debate on these matters and there is some hint of an attitude to "let sleeping dogs lie". Have we debated the merits of being pro-active rather than re-active across all of these issues listed above and I am sure that there are more.

THE POLITICS OF CONSTAINTS

There is a cycle of concern and action and plays on perception and reality. The public expresses concern about the impact of existing practices- this may be inflamed by media reporting.

- This results in political action.
- Which leads to new Regulations.
- Compliance then becomes a management responsibility and public reporting interest.
- Penalties and liabilities are then factors in reputation and management planning.
- Which pushes up investment.
- Which pushes up costs and tariffs.
- The public expresses concern about rising charges and this clashes with the desire for environmental action. The cycle continues with this dichotomy of improvement and cost.

Unrealistic Regulations may be ignored, but if they are accompanied by draconian penalties , the total cost becomes unacceptably high- whether it is utility service charges or product costs , where industry has been regulated.

In theory, all environmental Regulations must be based on sound scientific evidence and this should include risk analysis and this embraces cost - benefit analysis. However, even the interpretation of scientific evidence is susceptible to unconscious subjective judgement, which reflects the native culture of the interpreter. Scientific information often needs to be converted first to knowledge and then to wisdom by the application of experience and common-sense. When scientists disagree this has an unsettling effect on the public and there is a call for caution.

There is a place for political judgement, but it should not be disguised as genuine science. In political terms, this judgement may be described as the 'will of the people'. Our job, as professionals , is to make sure that this contribution is as well informed as it can be. The problem is that sometimes the rigorously scientific, pragmatic and political approaches become adversarial.

As an example let us imagine a biosolids operation and assess the length of time that it can continue. For this we need to know what the "cap" is and the rate of application which is required or permitted. The 'cap' may be dictated by a total load limit or a maximum permissible soil concentration or each regulated substance. The rate of accumulation may also be regulated by a surrogate maximum permissible concentration a substance in a specified rate of biosolids application. Thus, there is a regulatory minimum period of application, which is the conjunction of the relevant limits. However, the better the quality of the biosolids, the longer the operation can continue.

There is a very important issue of sustainability. It has been suggested by the author at previous WEF Conferences that the rate of application to a particular site should be such that it can continue for at least 50 years and preferably much longer! This period was derived from the concept of two generations safety margin; it also accords with the period of 30 to 50 years which underpins current guidance.

So let us further imagine an operation in which for each site it applies biosolids , it can continue for 400 years. However, the critics of the scheme may well argue against the 'cap' limit, but not against the rate of accumulation. The 'cap', limits which they espouse may restrict the operation to 250 years. The former may be strictly scientific and the latter may be scientific and political. The argument about the long - term issues may obscure the acceptability of current operations.

However, a millennium perspective informs us that by the year 3000, we have to have an alternative answer for the operation, if there is just one site. It may be to move to another site or find alternative ways of using the product. If it moves to another site, it will have to move on successively and the entire operation may cease with current limits after 20,000 years [assuming that any one time only 2 % of available land is in use], but if the alternative limits are adopted, it will cease after 12,500 years. Now, in this long term historical perspective, there is nought but "a blink of an eye "between these limits, so why argue against the tighter values. Of course the more stringent approach should be based on alternative interpretation of real evidence rather than whim or political motive. This pragmatic approach must not be a 'crank's charter'! Acceptance of this rather controversial and novel approach should be based on true wisdom rather than opposed by hurt pride.

This historical perspective may then aid immediate operations. It is not sacrificing the opportunities of tomorrow for the expediencies of today, but it is a recognition that alternatives to current operations have to be found sooner or later - so make it a little sooner . There will be economic consequences in the long term and maybe in the short term. However this example was based on the notion that the rate of accumulation of metals was unaffected , so the immediate impact on costs should be negligible One answer is to make the biosolids of such good quality that it can be used forever. This has economic consequences, which must be viewed against the millennial perspective

There is no doubt that the current concerns about food focus on disease issues and the politics are such that the effect is straight forward - no biosolid will be useable unless it has been treated to remove risk irrespective of the operational practices.

THE LONG TERM FUTURE

Sustainability is a concept in which all the environmental inputs have to be assessed, so the production of biosolids which can used for infinity or the use of distant land may cause dominant environmental effects . A time will come when there will be a need to assess the cost/impacts of alternatives versus the cost/impacts of producing the ultimate clean biosolids or of alternative utilisation/disposal methods.

The truth is that the energy, organic matter and nutrients in biosolids are too valuable to be wasted . One must question the thesis that by - product heat from incineration is truly environmentally beneficial when the energy equivalence of the construction and maintenance of the process is assessed properly.

Experiences in the world have shown that, in order to create biosolids of sufficient quality for infinite sustainability, it is probably necessary to regulate the use of chemicals in domestic situations and to change manufacturing processes discharging effluents to sewers . So, the question will have to be asked about the feasibility and cost of doing this. It would certainly require a perfect autocracy rather than imperfect democracy ; and even then human fallibilities would thwart complete success.

There are two other aspects of sustainability - nuisance and health risk. These require processing of the biosolids prior to use . As concerns about disease in the community grow , so the demand grows for hygienic practices in food management. The 'faecal aversion barrier' focuses attention on biosolids management practices and so the trend is towards 'hygienisation' of biosolids used in food production, which increases costs and energy demands of agricultural use.

It is necessary to set out the rules for using biosolids in agriculture so that all stakeholders can understand what is required . The challenge in doing so is to retain the concept and reputation that the product is a useful resource and not a waste which should regulated out of use . There is a danger that the regulations become so restrictive that the practice is killed off . It may be that the intention is to boost confidence and increase use , but the practical effect may be opposite . Regulations are under review in the EU and US and as these continents provide two majors sources of wisdom in the world and are represented in the workshop , a summary is appended .

Until now, agricultural has been a happy partnership between the least cost and most environmentally friendly option for the disposal of used-water solids. This partnership is coming under strain and alternatives are being adopted - for example , incineration in the Netherlands. Landfill and marine dispersal are unlikely to form part of long term strategies There are other impacts of alternatives besides energy consumption - for example incineration , vitrification , pyrolysis , protein recovery, etc. All leave residues which must be disposed wastefully or incorporated into construction materials . Whilst these residues could be applied to land, the same chemical restrictions will apply without the obvious benefits of nutrients and organic matter.

If the biosolids are used for growing non-agricultural crops, there is less concern about the chemicals in the biosolids . There is no evidence at all that current soil levels permitted in the EU or US cause problems with tree growth . The trees maybe used for wood as construction material or fuel source. If these levels are lessened for agricultural crops, the question will be posed as to whether these should apply to all land so that it can be used for agricultural purposes , if needed . The pragmatic answer with a sense of a long term perspective would be 'yes', if it aided current operations, unless it can be argued that land can be set aside for tree growing and would never be used for agriculture.

So what does the millennium 'crystal ball ' tell us ?

Agricultural use of biosolids will continue for a long time yet , probably with stricter controls on substances , but with full requirements for hygienisation. The controls on substances will not necessarily be directed towards infinite sustainability , although other environmental and resource needs may well achieve this. The limited sustainability envelope will close more quickly for large conurbations because of the cost / energy requirements of transport , However , in suburban , and particularly rural situations , there will be infinite sustainability , but this may require the phasing out of use of some domestic and industrial chemicals . The schemes will be heavily regulated and monitored by statutory and quality assurance schemes It is also likely the materials supplied to agriculture will be 'productified , so that they do not look like sludge .

It is possible that domestic use of the products will disappear , not because of any explicit risk , but because of the demands of the control schemes and the attendant records.

It may well be that in limited areas , land will be managed with infinite sustainability for forest growth, but which will never be used for agriculture.

Incineration will be the referred option for conurbations , so the fate of this sludge technology will be tied up with the wider fate of incineration. As a minimum , the thermal energy released will be used as a power source in used - water management or in the wider community The problem will be the disposal of the residual ash and this may be a key factor in the fate of this option .There will be demanding criteria for metals in the residues, particularly if they are applied to land . The selection of incineration will be on economic grounds rather than a need to dispose of contaminated sludge. For a whole variety of reasons the notion of contaminated sludges will disappear. Ashes lack organic matter and nutrients and so they are not favoured fertiliser supplements . They are likely to be disposed to landfill for a long time yet in many places - but this is likely to diminish as opportunities decrease and costs and unpopularity increase.

If the fate of ash is to be incorporated into construction materials, it may well be that this will encourage direct use of dried sludge in processes such as brick manufacture.

Other technologies for resource recovery are not likely to be common place for a long time yet , but as the balances of sludge management costs, commodity prices, and energy costs change , so these processes will become more common - place. For those of you who are science - fiction and cinema fans , you will know what I mean when I suggest that we might even see the day when we have ‘soylent brown’ - although not in our life - times. However , it is more likely that oil production will come first.

There are many other ideas , such as waterless sanitation systems and injection of liquid sludge into redundant oil well-fields and the construction of incinerators on redundant oil tankers and drilling platforms . None shows any signs of being one of these practical , but we should never be complacent ; remember what the early mainframe computer manufacturers thought about personal computers!!

CONCLUSION

The purpose of this paper is to be provocative and to challenge some of the traditional as well as contemporary attitudes. There is no doubt that the problems will continue to challenge managers of the future. There is a need to think about the integration of the solution of them with other environmental issues . Managers in the next millennium will have decide whether used - water solids management is a function of issues relevant to the water environment or of waste management . Indeed, should we drop the notion of waste completely and refer to ‘used materials’?.

The historical view of the use of organic matter in land has been subjective rather than objective. Digging or ploughing in organic matter was viewed as a natural process determined by practical experience rather than by scientific method. Biosolids use has now pulled a long way ahead of other materials and the question has to be posed as to whether this gap should now be closed.

To which domain does biosolids use belong - water, land or public health? It is all of them. There are many stakeholders . It is a partnership. The way in which that partnership is managed must be teamwork and, as such, must be a role model of good behaviour , which should be a beacon to wider society ,which is in desperate need for such models .

The paradoxes outlined earlier all come down to communication . We cannot step back and leave one community sector - the utilities - to get on and solve the problems . The stakeholder partnerships must take a shared responsibility . Biosolids and sludge management is not something which can be closed like some redundant industry, it is with us for ever and as such needs some extra special vision .

USE OF SLUDGE ON FARMLAND

Jens Aage Hansen* and Tjalfe Gorm Poulsen

* Department of Environmenatl Engineering, *Aalborg University, Denmark*
E-mail: Jaah@civil.auc.dk

100 YEARS TO MAKE A MANAGEABLE SCENARIO FOR SLUDGE IN AGRICULTURE

Copenhagen like so many other European cities at the end of the 1890'ties had trouble with night soil collection systems. They caused bad smell, spills from bins and carts, and costly and difficult to manage storage ponds within the city limits. Eventually the night soil was loaded onto trains that brought it to the farmers outside the city. After all, this was early recycling of nutrients and organic matter.

With sewerage the night soil "disappeared" and so did the recycling. "Tout a l'égouts" (everything down the drain) became the accepted strategy and direct disposal to receiving waters became the solution. But sludge appeared instead of night soil, when wastewater treatment was introduced. Since the second world war, Danish sludge production has been on a steady increase and so has recycling of sludge by both absolute and relative measures. In the early 1990'ties, sludge recycling to farmland in Denmark amounted to some 75%. Most of the remainder was incinerated and to a certain extent was heat recovered.

This recycling rate was by no means automatic or self-evident. As a matter of fact, heavy metals found in the early 1970'ties in compost from household waste composting plants caused concern to the extent that most of the plants stopped operation before 1980. Heavy metals were found also in sludge, but based on targeted industrial source identification, the levels of cadmium, lead and mercury were reduced so that effectively the heavy metal issue was contained. At the same time, studies on heavy metal epidemiology and mobility in soil formed the basis for new regulations that would protect groundwater and consumers and at the same time allow practically feasible sludge management. Recycling of sludge actually increased during the 1980'ties, particularly because of phosphorus recovery – and of course low cost to the treatment plant owners and farmers.

Pathogens in sludge were identified, e.g. salmonella and tapeworm. Studies were carried out on their partial degradation in treatment plants and final decay after a certain residence time in soil. In no case did a disease outbreak occur, where sludge was applied according to the regulations. In a few cases, where the regulations were not followed, tapeworm infected young grazing cattle. A farmer had used his slurry equipment to empty a camping site toilet collection tank. Without cleansing he afterwards applied farmyard slurry to the grazing field. The tapeworm outbreak was immediate. Thus the infection risk was real, but targeted and prescribed management could have prevented the disease outbreak.

Can this experience from past pathogen management be used also nowadays and in the future? It possibly can, but it seems necessary to provide new information to answer new relevant questions. E.g., to which extent can inactivation in technical plants substitute long residence time in soil? What new(?) pathogens or indicators should be controlled and how to monitor them? Do new patterns of tourism change the existing contingency plans? How can experience in one region be translated into regulations in other regions and climates?

Organic compounds, e.g. PAH, LAS, DEHP, are found in trace amounts in sludge due to their use in industry and households or as a result of atmospheric precipitation and storm water run-off. Here is a newer and rapidly growing problem in terms of sludge quality and its safe use in agriculture. It seems likely that new and more sensitive analytical equipment will pose questions that will demand time consuming studies and evaluations, before answers are given and safe sludge management procedures prescribed.

It is noteworthy that both pathogens and organic compounds are degradable by biological, chemical and physical processes. In this respect they differ from heavy metals, which are conservative and should be controlled mainly at the source through limitations or bans on their use. Interestingly, the provisional guidelines established in national regulations to control organic compounds prescribe limit concentrations to organic compounds as if they were conservative like heavy metals.

It would seem logical to accept the inevitable presence of pathogens and limited amounts of useful but hazardous organic compounds in sludge as produced by wastewater treatment. But it follows from the degradability of both pathogens and hazardous organic compounds that their fate in various processes in technical plants and in soil must be further studied to develop new and innovative sludge management strategies. This may involve change of procedures in industry and households, new sewer and sewage management strategies as well as new quality criteria for sludge as an end product for agricultural use. And several other end uses should be considered as well.

Possibly there is a need for a complete reassessment of appearance, transport, transformation and fate of pathogens and hazardous organic compounds in wastewater and sludge. It could be much like the heavy metal approach in the 1970'ties, but the task is more comprehensive, given the number of compounds and pathogens and their non-conservative nature. Phasing-out plans for selected compounds may work, but traditional source control measures seem less relevant for the hazardous organic compounds and the pathogens.

ALTERNATIVE SCENARIOS

Agricultural use of sludge for nutrient recycling is a reference scenario in many countries. However, inherent risks regarding human health and environmental quality as well as the appearance of new technology to process sludge suggest new and different scenarios. These could involve processes such as incineration, thermal gasification, anaerobic digestion and composting as well as enhanced dewatering or combinations thereof.

Sludge properties

Different treatment options for the sewage sludge are evaluated based on their energy production, CO_2 balance, fertilizer production and potential for reduction of pathogens and organic chemicals. The sludge is assumed to contain 5% dry matter and has an energy content of 22MJ/kg combustible dry matter. Sewage sludge normally contains 48 kg N and 33 kg P per ton dry matter. It is assumed that 50% of N and 100% of P in the sludge is available for plant uptake. It usually has an ash content of 40% of the dry matter content. Mechanical dewatering of the sludge requires 100.8 MJ/ton for dewatering from 5 – 20% dry matter content, 114.3 MJ/ton for dewatering from 5 – 40% dry matter content and 184.8 MJ/ton for dewatering from 5 – 60% dry matter content.

Treatment options

Two different treatment options with respect to sewage sludge treatment are considered. These are: a) no additional treatment and b) energy production from incineration.

Incineration is assumed to convert 99% of the combustible (organic) matter in the sludge under production of 22% electricity and 63% heat from net energy released from the combustion. It is assumed that the heat contained in evaporated water is not utilized, as most present incineration facilities are not equipped with condensation facilities because of corrosion problems connected to such heat utilization.

Environmental impacts

Consumption of electricity (typically produced from coal) and heat (typically produced from oil) produces 211 gCO_2/MJ and 85 gCO_2/MJ, respectively. Transport by truck has an emission of 75 gCO_2/ton, kilometre and uses 0.9 MJ/ton, kilometre (oil). Production of chemical fertilizer requires 50 MJ/kg (as electricity) for N and 40 MJ/kg (as oil for transport) for P.

Scenarios

Two sets of scenarios are considered for evaluating treatment corresponding to each of the above two options. For all scenarios a 20km distance for transport of the treated sludge is assumed.

Set 1:
1) No additional treatment of the sludge and direct application to farmland (base case)
2) Mechanical drying to 20% dry matter and direct application to farmland
3) Mechanical drying to 20% dry matter and disposal at landfill (fertilizer content not utilized)

Set 2:
4) Mechanical drying to 20% dry matter, incineration and disposal of ash at landfill
5) Mechanical drying to 40% dry matter, incineration and disposal of ash at landfill
6) Mechanical drying to 60% dry matter, incineration and disposal of ash at landfill

For each scenario the total energy production, N and P contents and CO_2 emission reductions are calculated using the parameters given above. The results in terms of energy production, fertilizer production (resource parameters), CO_2 emissions, and pathogen and organic compound reductions (environmental parameters) are shown in Table 1 below. Energy production and CO_2 emission reductions for each scenario include the energy and CO_2 emissions that are associated with production of equivalent amounts of chemical fertilizers (N, P) for each scenario.

Table 1. Energy production, N, P production, CO_2 emission reductions, pathogen reduction and reduction of organic chemicals. All parameters are given in relation to one ton of sludge with 5% dry matter content unless otherwise stated.

Scenario	Energy MJ/ton	N kg/ton dry matter	P kg/ton dry matter	CO_2 reduction kg/ton	Pathogen reduction	Org. compound reduction
1	**108.0**	**24**	**33**	**16.7**	**No**	**No**
2	20.7	24	33	-3.3	No	No
3	-105.3	0	0	-21.6	No	No
4	419.0	0	0	39.9	Yes	Yes
5	448.2	0	0	36.3	Yes	Yes
6	390.1	0	0	14.4	Yes	Yes

Discussion

It is clearly seen from Table 1 that disposal of the untreated sludge at a landfill (scenarios 3) is the least attractive option seen from both a resource and environmental point of view. This is because the positive impacts on both the resource and environmental parameters caused by the utilization of fertilizer contained in the sludge do not appear when the sludge is disposed of at a landfill.

Incineration yields more energy and CO_2 emission reduction, and it gives 4 – 5 times as much energy and emission reduction as scenario 1. Incineration further has the advantage that all pathogens and toxic organic compounds contained in the sludge are destroyed. It is also seen that dewatering from 40 to 60% dry matter content is not advantageous from an energy point of view. The indicated potential for pathogen and organic compound reductions listed in the table refer to sludge treatment only, it is noted that further reductions can be achieved after application to land depending on soil conditions.

As the primary treatment methods (anaerobic digestion and activated sludge process) both have an important impact upon the energy and CO2 budgets they should be included in the comparative evaluation. Also alternative secondary treatment methods such as composting and thermal gasification should be included in the further assessment of alternative sludge management scenarios.

ISSUES FOR FURTHER CONSIDERATIONS

- Enhanced dewatering seems interesting in relation to thermal processing. The dewatering energy requirements must however be limited through modifications of the sludge (conditioning) or improved machinery design. Such improvements seem feasible.

- Thermal processing and energy recovery seem interesting options, because an effective barrier to transfer of pathogens dispersion and hazardous organic compounds is thereby established. However, to recover resources such as phosphorus, more work is necessary. The reductive processes seem to offer possibilities not yet exploited.

- Composting, though not yet included in the examples above, has proven effective in degradation of hazardous organic compounds such as LAS, PAH and DEHP. It also inactivates pathogens and preserves phosphorus. It deserves more attention where land use of sludge is to be considered. This applies in industrialized as well as developing countries.

- District (decentralized) solutions to collection and treatment of wastewater seem interesting for new system solutions, in particular in major cities in development areas, where sewerage is not established. They will provide new sludge management options in terms of better wastewater and sludge quality control. Also, the trunk sewer network will be reduced and more effective use achieved of the storm water system.

- The potential for degradation of organic compounds and inactivation of pathogens in the soil environment is an important issue in sludge management as sludge application to farmland may be more attractive if such processes take place.

- There is reason to pursue land application of sewage sludge as an important option in sludge management. Environment and health concerns will emphasize the need for cautious use in industry and households of the sewer as a resource recycling facility. Efficient sludge treatment and knowledge on transport and transformation processes in soil will be assessing means of sustainable sludge management. This issue of sludge in organic farming may be used as test case for identification of appropriate land use and limits to sludge soil application.

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THE PRODUCTION AND UTILIZATION OF CONSTRUCTED SOIL CONDITIONER/COMPOST MADE FROM WASTEWATER SLUDGE AND OTHER COMPONENTS

Ludovico Spinosa
Chairman of IWA Specialist Group on Sludge Management
c/o C.N.R., Via De Blasio 5, 70123 Bari, Italy

Carmine Carella
Environmental Consultant, Via Loquercio 49, 70012 Bari-Carbonara, Italy

INTRODUCTION

The management of Wastewater Treatment Sludge (WTS) in an economically and environmentally acceptable manner is one of the critical issues facing the society today, due to the very fast increase in their production, as a result of extended sewerage and new advanced wastewater treatments. Moreover, during the last few years there has been a worldwide movement toward a common strategy for any kind of waste, with the priorities of reusing waste materials and taking advantage of their energy content.

Additional problem arises from the fact that sludge is a material difficult to be handled because, from a physical point of view, it is a paste-like material that behaves, at the origin, more similarly to a liquid and, after treatment, to a solid one.

Available and well-known practices for the management of WTS are:

- Direct land application, including spreading on agricultural and forest land, disturbed soils for reclamation, dedicated beneficial use sites, etc.;
- Composting;
- Thermal processing;
- Land filling.

Land application is likely to remain as a major option for WTS disposal, especially for sludges deriving from treatment works less contaminated by toxic compounds and located close to the disposal site. However, this alternative is subjected to a great variability over time, depending on crop type and weather conditions, while sludge production is continuous.

For above reasons, the agricultural utilisation of WTS after its composting is a preferred option, mainly because it has the advantage of producing a material which can be more easily stored, transported and used on times and sites different from those of production. Composting also involves the production of a more safe and hygienic product. The more constant and controlled quality of compost, in comparison to what happens in direct agricultural utilisation of WTS, is also of major interest.

PROCESS DESCRIPTION

The main operating variables affecting the composting process performance are:

- Moisture content, to conveniently support the microbial activity (optimal values range 50 to 60%);
- Carbon/nitrogen ratio, to avoid slow processing (occurring at high C/N ratios, >30) or ammonia volatilization (at low ratios, <20), considered that microorganisms utilize about thirty parts by weight of carbon for one part of nitrogen (optimal 25-30);
- Aeration, to permit metabolism and respiration of microorganisms and oxidation of organic molecules, and avoid development of malodours;
- Temperature, to obtain pathogens reduction without the inhibition of microorganisms growth (optimal 55-60 °C);
- pH, even if a quite wide range is acceptable (5.5-8.0).

It can be seen that the best operating conditions are met when WTS is sufficiently dewatered and mixed with proper bulking materials. Dewatering allows microbial activities to be correctly developed and necessary physical consistency obtained, while bulking materials provide, together with a higher physical consistency, the carbonaceous substrate to reach the optimal C/N ratio, being the sludge C/N typically below 20, often less than 15.

Several techniques can be adopted for WTS composting. They mainly differ in aeration and mixing modalities, but all of them practically consist of the following basic steps:

a) Addition of bulking agents, to provide a sufficiently porous and soft mixture suitable for processing,
b) Aeration and attainment of a temperature of about 60 °C, to obtain pathogen destruction and moisture reduction,
c) Further storage (curing), for completion of stabilisation,
d) Refining treatments, generally including separation and recycling of bulking agents, screening, granulation and packaging.

General categories of composting plants are:

1) Open systems, including turned pile with natural ventilation, static pile with forced aeration, confined with mechanical turning and forced ventilation;
2) Closed or in-vessel systems.

In open pile systems the composting material is arranged in windrows and aerated either by simply turning the mass (turned pile) or by forced ventilation (aerated pile). Confined and in-vessel systems, both horizontal and vertical, comprise mechanical equipment which provides a better control of the main operating variables. Advantages of closed systems over open ones include (i) more effective odour control, (ii) indoor operation, (iii) insensitivity to climate and (iv) low labour requirements.

It must be evidenced that composting is the typical process usefully applicable for the combined management of WTS and Municipal Solid Wastes (MSW), so avoiding specific technical problems and considerable diseconomies deriving from their separate handling. In fact, by co-composting WTS with the wet fraction of MSW, a better final product and overall process performance are obtained because the relatively higher solids content and C/N ratio (>30) of MSW allows:

- The low C/N ratio of WTS (<20) to be increased to optimal value,
- The proper moisture content to be met without a high dewatering degree of WTS,
- The addition of supporting material to be avoided.

However, the presence in MSW of no-compostable materials, such as glass, plastic, iron and aluminium products, must be avoided, so the separate collection and the effective separation of above MSW components is a fundamental prerequisite for a successful composting operation.

COMPOST CHARACTERISTICS AND APPLICATION

Composting is aimed at producing an organic fertilizer containing balanced quantities of all those elements, like organic substances, fertilizing elements, moisture and trace-elements which are useful to crops.

The potential starting materials for the production of compost can be municipal sewage sludges, industrial sludges having similar characteristics to municipal ones, the wet fraction of municipal solid wastes, and other agricultural wastes or by-products, such as grape residues, exhausted olive residues, sugarbeet residues, green residues, distiller's residues and tinning-factories wastes, whose commercial value is very low and disposal could represent a very remarkable environmental and economic problem.

Nutrition of crops is the first action directly exerted by the compost. Soon after having been spread on the soil, this product starts to act through its micro-flora: the organic matter is mineralized, whereas nitrogen, phosphorus and potassium which are present in the non assimilable form are removed, thus providing the crop with nutrients and trace-elements. In this way the elements assimilation is total and represents a true economic advantage.

Moreover, the structure of the soil is also improved, because organic matter:

- makes sandy soils consistent;
- loosens soil compactiveness;
- increases water absorption.

An enhanced imbibition capacity, together with a major water retention, are some of the effects of the above mentioned actions. Benefits are addressed to the root system, resulting in a better transpiration and oxygenation. Soil exchange capacity also increases and this is a very important factor which shows soil fertility, so allowing the transfer of nutrients to the crop.

Application rates depend on different factors, such as:

- organic matter content, pH and structure of the soil;
- crop type (open field, greenhouse, root-crop, tuber crop, etc.);
- target (nutrition and/or soil restoration);
- seasonal period (spring/autumn).

Typical reported application rates for an italian commercially available product, are 1,000-1,500 kg/ha for industrial crops (maize, sunflower, soya-bean, tobacco, strawberry, rice, sugar-beet, cotton, colza), 5-7 kg/tree for fruit plants (apple, pear, almond, plum, peach, cherry, nut, walnut), 1,500-3,000 kg/ha for solanacenes (tomato, potato, pepper, egg-plant) and 8-100 kg/m^2 for playgrounds (football courses, golf courses). Results of a spanish product as organic fertilizer has been proven at dosages from 4,000 to 10,000 kg/ha.

Generally speaking, the action of 100 kg of compost can be considered corresponding to that of 3,000 kg of farmyard manure.

CONCLUSIONS

Land application is the major option for recycling wastewater treatment sludge and other organic wastes, and recovering the useful substances contained in them. Utilization of such wastes after composting is to be preferred because compost has the advantage of producing a more safe and hygienic material that can be more easily stored, transported and used on times and sites different from those of production.

The use of this product involves organic matter, nutritional and micro- and macro-elements to be supplied to cultivations, and water needs reduced. Compost also demonstrated to have many advantages, if compared to other fertilizers, like richer and better harvests from an organoleptic viewpoint, healthier plants and crops, less need of water for irrigation, improved soil structure, reduction of chemicals dosage, protection of the environment. Other advantages of this product, if compared to farmyard manure, are that it contains a higher amount of bacteriological flora of a much better quality, is practically free from pathogens, can be much easier spread through the mechanical fertilizer distributors and has a more balanced chemical composition.

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ALTERNATIVES TO AGRICULTURAL USE OF SEWAGE SLUDGE

Prof. Helmut Kroiss

Institute for Water Quality and Waste Management, Vienna University of Technology, Karlsplatz 13/226.1, 1040 Vienna, Austria
E-mail: hkroiss@iwag.tuwien.ac.at

ABSTRACT

In this paper alternatives to agricultural use of sewage sludge are discussed., where the expression "alternative use" stands for processes that yield positive aspects in terms of economy and/or ecology. The author discusses economic and ecological criteria of "alternative processes" and applies them to processes which aim at an energetic or a material use of sewage sludge. It is shown that the economic value of sewage sludge is low as long as agricultural use is excluded. Energetic use is an economically and ecologically competitive solution in large agglomerations, but it poses several problems in decentralised areas. Material use via recovery of low entropy material from the sludge results in high energy and/or equipment costs.

KEYWORDS

Sludge incineration, entropy, energetic use of sewage sludge, agricultural use

INTRODUCTION

All the modern treatment processes commonly applied for municipal waste water result in sewage sludge. This is an important characteristic of this material, as sewage sludge can be classified as a "reliable" resource at least for the large agglomerations (cities). There, no alternative solution to conventional sewer systems for the collection and treatment of the waste water is available. This infrastructure achieves the main goals in regard to hygiene, flood protection and water protection. As there is a strong trend towards an increase of the world's population in large agglomerations we can assume, that in the future the majority of the population (up to 70%) will be served by a relatively small number of large "centralised" systems while for the rest of the population living in rural areas a large number of small treatment systems will have to be operated. This trend has strong implications on the sludge treatment and disposal methods.

In the recent years completely new solutions for the domestic "waste water" problem have been under development aiming at a recovery of nutrients (N, P, K) and a reduction of water consumption for transport of the waste. These systems do not rely on central treatment facilities but aim at a local treatment and reuse of water and "sludge" which will have to be handled also for these new systems. The basic idea is to avoid "alternative" use of the sludge but to recycle it to the soils.
"Alternatives to agricultural use of sludge" has to be defined. It does not mean use of sludge for landscaping e.g., where the recycling of nutrients and the organic content of the sludge are the decisive criteria. The expression "use" implies a positive aspect in terms of economy and/or ecology. Considering these aspects the valuable components in regard to alternative use of the sludge can be reduced to the calorific value of the organic fraction and the potential value of the inorganic components as phosphorus, heavy metals and the mineral content.

CRITERIA FOR ALTERNATIVE USE

In any case the most important criterion for the “use” of sewage sludge is the economic value of the sludge. It is very low as it is a mixture of thousands of compounds. The inorganic fraction of the solids is a mixture of a great variety of minerals, small grain fraction, with strong variations in the daily load and composition. The organic fraction is a mixture of thousands of organic compounds, too. It also contributes to about 50 % of the dry solids. The composition also changes over time in quality and quantity. The value of the organic fraction for alternative use is it’s calorific value. Depending on the sludge treatment the amount of water associated with the combustible organic fraction can vary to a large extent. This has great influence on the energy balance of any kind of energetic use.
The most valuable element in the sludge normally is phosphorus, as it is a limited resource and can be recovered even after incineration. The heavy metals associated with the solids could be recovered from the sludge, but their concentration in the sludge is so low, that it will not be economically feasible at least at present time, where natural ores with much higher concentrations are available.

The second “economic” argument is linked to the need to get rid of this “reliable resource” which is at the same time an important waste load. The economic criterion then is the minimisation of the costs for sludge disposal. In most of the cases alternative use of the sludge is only a side effect in order to reduce the costs.

In terms of ecology the criterion has to be based on the two principles of thermodynamics: the conservation of material and energy and the entropy law. Especially the second law of thermodynamics seems to be more interesting for decision making than the first. Sewage sludge from conventional mechanical biological waste water treatment is a product from degradation processes, it is characterised by a high level of entropy (disorder) and a low calorific value. Any recover of valuable low entropy materials will result in high energy requirements.

In regard to carbon dioxide production influencing our climate, there is – on a long term prospective – no difference whether the sludge is used in agriculture or it is incinerated. Any use of low entropy fuel (oil, gas, cole etc.) in order to recover low entropy material will increase CO_2 production as long as these materials can be recovered from lower entropy levels (ores minerals) as compared to sewage sludge. E.g. the use of pure chemicals for metal recovery or the use of fossile energy to melt the sludge (glass production) will probably strongly increase the overall entropy. Nevertheless, there is quite a difference between co-incineration of sludge in cement kilns and the sludge melting process, as in the first case all the possibly valuable compounds are heavily diluted in the cement (increase in entropy) while by the second process the concentration of all inorganic compounds is increased (reduction of entropy). For the comparison of different sludge treatment processes a new evaluation procedure has been developed by RECHBERGER (1999), who created the so called SCE (substance concentration efficiency) which represents a quantitative tool to compare different waste treatment processes based on the second law of thermodynamics. The SCE comprises all the processes involved until the final fate of a waste as sewage sludge e.g. digestion, dewatering, transport, incineration, etc.

The ecological criteria are not in accordance with economic criteria in principle. But in many cases both criteria lead to the same conclusions if different technical solutions are compared.
An important methodological aspect in comparing different “uses” of sewage sludge is contained in the boundary definition of the process. Using e.g. life cycle analysis it is recommended to define the start of the process evaluation after thickening (primary and secondary sludge) and to define the end at the final disposal of all materials and energy contained in the sludge.

As the definition of the boundary conditions and the evaluation of the ecological effects can easily be decisive for the outcome of all considerations and calculations I personally can agree to a large extent with a modern saying: “Economic criteria are the worst criteria for the decision on ecologically sound solutions but they are the best available ones”. Further on it always has to be considered that specific local conditions and the size of the plants often play the decisive role in process selection.

ENERGETIC USE OF SLUDGE

For all considerations in regard to energy in the waste water business the COD mass balance can be used as the most adequate methodology. It can be shown that irrespective of the kind of organic compounds 1 g of COD corresponds to about 14 kJ of energy which can be recovered by complete oxidation (combustion enthalpy). If we assume a daily COD load of 110 g COD/population equivalent in the raw waste water about 100g/p.e./d can be removed by (mechanical-) biological treatment. By primary sedimentation up to about 30% of the COD can be transferred to the primary sludge, which then contains about 30 g of COD/p.e./d. By chemical enhancement this transfer can be increased up to about 70%. Biological treatment results in a transfer of the pollution to secondary sludge production. If primary sedimentation is applied secondary sludge will contain between 25 and 35 g COD/p.e./d depending on the sludge age, the temperature and the nitrogen removal requirements. If no primary sedimentation is applied secondary sludge will contain between 40 and 55 g COD/p.e./d depending on the required treatment efficiency.

Irrespective of the biological sludge stabilisation processes applied (conventional aerobic or anaerobic) a minimum of about 25 g COD/p.e./d will remain in the stabilised sludge. Sludge stabilisation by incineration will result in a nearly complete destruction of organic material i.e. COD in the ashes should be nearly zero.

The total energy content of the dry solids in the sludge depends on the waste water treatment and the stabilisation processes applied. By anaerobic digestion part of this energy is transferred to the biogas produced. The maximum achievable total energy content of the sludge is in the range of 65 g COD/p.e./d which corresponds to about 910 kJ/p.e./d or about a continuous “power production” of 10 to 15 W/p.e. If we compare this figure with the total primary energy consumption per inhabitant in western Europe of about 5 to 6 kW it turns out that sludge incineration only can contribute to about 2°/oo which is within the accuracy of measurement.

The energy balance of a sludge incineration plant strongly depends on the water content achieved by thickening, dewatering and drying. The energy requirements for these processes increase with increased dry solids content of the sludge before incineration. At the same time the fuel consumption for sustaining the combustion process decreases. The minimisation of the energy requirements for sludge incineration is a classical optimisation problem.

Incineration for energetic use of the sludge can be performed in different ways:

- raw sludge incineration (primary and secondary sludge)
- incineration of anaerobically stabilised (digested) sludge
- a mixture of both (digested primary and raw secondary sludge)

For raw sludge incineration it has to be considered that raw sludge has to be incinerated within about one day after its withdrawal from the treatment process in order to avoid severe odour and dewatering problems. Raw sludge incineration therefore needs a very flexible operation and control system, as sludge quality and quantity will be extremely variable from day to day even from hour to hour (e.g. storm water events). Another consequence is that at any time the capacity of the incineration plant has to correspond to the maximum sludge production. Such a plant seems to be only feasible for large treatment plants in close neighbourhood to it. In several large raw sludge incineration plants it could be shown that with mechanical dewatering (>35% DS) a self sustaining combustion can be achieved without or with only rare addition of external energy sources (oil, gas).

If sludge has to be transported to the incineration plant over longer distances it will be necessary to store it before incineration. This is only feasible with stabilised sludge. The stabilisation can be achieved by the biological processes but also by sludge drying (>95%). The only problem is, that sludge drying needs thermal energy which is available at the incineration plant at low price while at decentralised plants this often is not the case. If there is enough storage and equalisation capacity (e.g. by anaerobic sludge digestion) the capacity of the plant can be designed for the maximum two weeks mean load. If biologically stabilised sludge has to be incinerated after mechanical dewatering a self sustaining combustion can only be achieved with the addition of external energy sources (e.g. the biogas from anaerobic digestion). If the sludge is dried no external energy source will be needed.

Economically and ecologically sound incineration plants for sludge have a minimum capacity of about 1 to 2 t DS/h, or about 40 to 50 t DS/d. Such a capacity will be able to cope with the sludge production beyond about 300 000 p.e. Sludge incineration plants can be combined with waste incineration but this is not a very easy technical problem. One solution is to incinerate special fractions of the domestic waste (energy rich fraction) together with the sludge.

Alternative methods for the energetic use of the sludge is pyrolysis. Under high pressure and high temperatures under anaerobic conditions part of the organic fraction of the sludge is converted to an oily fraction, a solid residue (coke) and a waste water. It seems to be doubtful whether such a process is environmentally and economically competitive.

MATERIAL USE OF SLUDGE

The organic fraction is not relevant in this respect as its “value” and “use” has already been discussed with the agricultural and energetic use in the respective chapters. There are some ideas to recover e.g. vitamin B_{12} from digested sludge, up to now without practical relevance.

If we consider the mineral fraction either mixed with the organic fraction or after incineration as ash and slug the mass flow has little relevance for the society. Actually we annually accumulate about 8 t of mineral construction material per inhabitant while the inorganic sludge production is in the range of 10 kg/p.e./a, which is far below the accuracy of any mass balance. This is also the case if we consider only the cement production using a co-incineration process in cement kilns. Having this in mind it is difficult to evaluate the use of the inorganic fraction from a macroeconomic point of view, where it obviously is a negligible resource.

The co-incineration of dewatered sewage sludge in cement kilns can be an economically competitive solution, as it is applied e.g. for the sludge from the city of Zurich. From the entropy point of view this solution leads to a strong increase of the dilution factor of all the valuable compounds of the sludge i.e. a marked increase in entropy. The energy potential of the sludge is used and the adsorption capacity of the cement fraction for potentially hazardous compounds in the sludge can be classified as positive effects. In most of the cases cement factories are not situated very close to treatment plants, which results in the need for transport and storage.

Another method to “use the inorganic fraction is the melting process which was first applied in full scale in Japan. The solid residues of sludge incineration are subject to temperatures where the mineral fraction is melted. The melted sludge can be used as an industrial glass. This process needs about 0,25 l of oil, so that from the energetic point of view this is a severe drawback. The end products are environmentally sound as all possible hazardous compounds of the sludge are imbedded in a matrix with high resistance to re-solubilisation. The volume of the residues is also very small. The main problem with this process is the economic competitiveness as the melted sludge products have to compete with low cost materials.

CONCLUSIONS

The economic value of the sewage sludge components is low as long as agricultural use is excluded. The mixture is so complex that the recovery of low entropy material from the sludge will result in high energy and/or equipment costs. The organic fraction can be used for energy production in incineration plants. The energy contained in the sludge can be neglected as compared to the actual primary energy consumption. The economic value of the inorganic fraction is even less important as compared to the actual consumption for construction purposes.

The main problem with sewage sludge is that it is a reliable resource which has to be reliably “used” or disposed of. Alternative use of sewage sludge therefore has always to be considered within the frame of reliable sludge disposal methods. The “use“ of sludge in most of the cases will be a method to minimise the cost. Even if this will not be in accordance with all ecological aspects the economic evaluation cannot be neglected and in many cases reflects also sustainability. In regard to the methodology to find the best solution for sludge treatment and disposal the economic evaluation contains less assumptions than the ecologic one (e.g. life cycle analysis).

From practical application it can be concluded that for large agglomerations sludge incineration with high quality gas cleaning is an economically and ecologically competitive solution to use the energetic value. The most advantageous solution seems to be the raw sludge incineration which needs the highest level of operational experience and control equipment.

The central incineration of the sludge from decentralised treatment plants poses several problems which decrease the economical and ecological competitiveness. For small treatment plants in rural areas incineration will not be competitive to agricultural use.

A completely different concept of waste water production and disposal by separation at the source (urine, faeces, grey water) with decentralised treatment facilities and local water cycles will not change the amount of solids produced very much. It only shows up that “alternative use of sewage sludge” (solid fraction) with the existing processes will not be advantageous, while agricultural use, maybe, will be more successful.

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WASTEWATER AS A RESOURCE: WHAT IS THE FUTURE?

Valentina Lazarova

Lyonnaise des Eaux- CIRSEE, 38, rue du Président Wilson, 78230 Le Pecq, France. E-mail: valentina.lazarova@lyonnaise-des-eaux.fr

INTRODUCTION

Growing water scarcity, population growth, fast urbanisation and mega cities development, increasing competition among users and growing concerns for health and environmental protection are the main trends of the new millennium that would seriously challenge water professionals. In order to deal with and safeguard water for the next generations, the integrated management of water resources is becoming the leading strategy worldwide. This strategy entails a series of political, legislative, social, economic and technical initiatives, which aim at better managing water resources and their quality in direct relationship with the policy for environmental protection and economic and urban planning. One of the main features of this new management policy is the concept of cooperation between the various sectors to maintain the equilibrium between the needs, stemming from human activities and the requirements of nature. Policies are no longer confined to national borders, but seek to achieve a regional and global balance. In this context, wastewater reuse becomes a key element to counter the negative quantitative and qualitative points of impacts between the anthropogenic and natural water cycles, to avoid the increasing pollution of natural freshwater resources, to provide low cost alternative resource for the different sectors of human activities, and thus, to close the loop between the two water cycles.

The integration of wastewater reuse in the natural water cycle requires the implementation of appropriate treatment technologies, stringent quality control and a better understanding of the risks inherent to each type of reuse. The new requirements, which apply to the quality of reclaimed water, make it necessary to establish a convergence of wastewater and potable treatment techniques. Today, technical advances make it possible to obtain from wastewater the quality of recycled water required for almost all types of use. However, there are still economic constraints, such as the competitiveness of recycled water with other resources. Therefore, the major role of reuse in the overall policy of water management can only be fulfilled once the appropriate administrative, regulatory and financial mechanisms have been established. A flexible water management policy can ensure the competitiveness of reuse as: (1) the lower cost and drought-proof alternative resource available near the point of use, (2) a unique and inexpensive solution for pollution, (3) a complementary resource for coastal areas where discharges into the sea are irreversible, (4) a viable alternative to the transportation of natural resources over long distances, (5) a balancing factor in the conflicts between the requirements of different sectors, ensuring water independence, (6) an important element in the development of major urban and rural settlements, (7) a solution for restoration of polluted resources and lost wetlands.

ECONOMIC AND FINANCIAL CONSTRAINTS: NEW GLOBAL TOOLS AND CONCEPTS FOR WASTEWATER REUSE DEVELOPMENT

In the next few years, water industry should develop new concepts for sound comprehensive water management to meet the raising new challenges: to satisfy water demand, to meet quality requirements, protect public health and environment, to manage water within its complex cycle, as well as to achieve these objectives in regions and countries with different population density and income. As the best higher-quality water sources become limited, water supply utilities are forced to consider options including wastewater reuse. Moreover, the more stringent wastewater discharge standards motivate local governments and wastewater agencies to implement wastewater reuse to assess the true value of treated wastewater and to evaluate it as a cost competitive solution compared to transportation over long distances or sea outfalls. Finally, water reuse management should be considered in close relationship with water resource management and conservation of ecological assets. Recreate lost wetlands or depleted drinking water resources would be in the future one of the major wastewater reuse application.

A critical element for the success of any water reclamation project is its affordability and financial viability. In general, the lack of funding is the major constraint for the implementation of wastewater reuse practices. For this reason, the majority of water reuse projects have been developed on the basis of subsidies and grants. Public/private partnerships appear as another solution to establish appropriate financial plans, cut public sector deficits, promote investments and ensure a better water resources management with efficient wastewater reuse. As a rule, wastewater reuse projects are under-evaluated and significant opportunities for beneficial reuse are lost. The main reason for this is that wastewater reuse is not considered as a part of the integrated water management with numerous monetary and non-monetary benefits compared to other alternative solutions.

The main needs for new global tools and concepts related to wastewater reuse as an element of the integrated water planning are:

1) Develop and apply macro-economic approaches for evaluations of wastewater reuse, including all the benefits for the economic development, watershed protection, health and environment protection and natural water cycle equilibrium.
2) Adapt or develop integrative modelling frameworks and integrated social-economic-technical models as decision-making tools for the choice of the most appropriate water management scenario for short- and long-term planning.
3) Assess the environmental impacts of wastewater reuse using modelling tools for aquifer recharge, soil impacts, wildlife conservation, and bathing and sensitive-zone protection.
4) Implement new wastewater management concepts as decentralised treatment and multi-quality water production to optimise the overall costs and benefits.

In an attempt to optimise water planning and management at the scale of a hydrologic unit, integrated technical-economic models and decision-making tools have been developed, enabling the comparison of different water management scenarios. Similar tools would be applied to compare wastewater reuse costs to other alternative solutions, using a macro-economic approach with a tentative evaluation of water reuse benefits for the long-term. For example, such a tool has been applied in the European *CatchWater* Project to simulate and evaluate the appropriate scenario for wastewater reuse. Multiple criteria have been proposed to evaluate the technical, economic, environmental and social aspects of wastewater reuse. The methodological approach is as follows: (1) investigate the key factors influencing wastewater reuse, including climate change, advanced water/wastewater treatment technologies, impacts of standards and regulations, water resources scarcity, economic issues (water prices, willingness to pay, available subsidies), public attitudes and environmental constraints; (2) evaluate the economic, social and environmental benefits of wastewater reuse with monetary and non-monetary criteria; (3) compare wastewater reuse scenarios, and include other alternative resources such as seawater desalination, mobilisation of new resources or transportation at long distances.

Despite the application of macro-economic approaches in the evaluation of wastewater reuse, some other new concepts can contribute to the successful implementation of sound wastewater reuse practices: (1) decentralised wastewater treatment and reuse using covered modern treatment facilities in urban areas or low-tech facilities in dispersed rural areas and (2) production of multi-quality recycled water for various reuse purposes. The first concept not only provides alternative recycled water at lower costs due to significant savings for construction of large sewers and distribution networks, but also is an important contribution to environment protection, beautification of cities and economic development. The second concept enhances the diversification of water reuse services and satisfies client requirements at an optimal cost.

By definition, the decentralised wastewater concept requires the use of appropriate treatment and disposal technologies, taking into consideration current and future needs of the community. This new solution addresses the needs of both sewered and unsewered areas in a more comprehensive, cost-effective and environmental-friendly way. The main advantages of this approach provide the following:

- A cost-effective option for rural areas and low population density communities, which avoids the cost of large sewerage systems and takes into account the possibility of using low-tech extensive treatment processes;
- watershed and water resource protection avoiding the large transfer of wastewater;
- higher flexibility and potential to provide the most appropriate solution for specific site conditions, such as high population density areas and shallow bedrock or shallow aquifers, including the possibility to use individual septic tanks, shared or clustered treatment systems or even centralised systems where appropriate;
- Both environmental protection and a cost-effective technical solution for urban and ecologically sensitive areas by the implementation of advanced treatments in compact, covered buildings, including odour treatment, nutrient removal and disinfection;
- The promotion of wastewater reuse and recycling for various purposes near the point of use.

The last two points are crucial for the development of water-scarce regions. Significant benefits and cost savings can be achieved, especially in unsewered areas.

The production of multi-quality recycled water for various reuse purposes, and in particular, the production of high quality water for industrial purposes and aquifer recharge, contributes to faster payback of the wastewater recycling facilities. In general, the sale price of recycled water for industries and urban users is higher, compared to the charges for farmers. It is important to stress however, that agricultural irrigation is characterised by the higher-water demand and the lower-economic value, which is usually subsidised by local or national governments with only partial recovery of treatment and distribution costs.

TECHNOLOGICAL INNOVATIONS AND TECHNICAL CHALLENGES FOR WATER REUSE

The latest results of research with state-of-the-art technologies and a multidisciplinary expertise have been harnessed in the service of water. The return of water back to nature is a difficult and complex task. A formidable goal would be achieved of ensuring the production of millions of cubic meters of purified and ultra-pure water from a wastewater at lower costs.

The numerous state-of-the-art technologies enable wastewater to become a resource to replace water from the natural environment. Reliable and effective treatments can be easily adapted to the specific needs of different uses. The inclusion of such systems into long and medium-term water planning is an indispensable condition for the successful development of wastewater reuse practices.

The level of treatment is chosen according to the standards and legal requirements and according to the type of reuse envisaged. In this way, the same treatment objective can be met by using either intensive technologies or extensive technologies, which are similar to natural treatment mechanisms. The final choice of a process will depend on technical and economic considerations, as well as on the local conditions (infrastructure, uses, available space, plant capacity, etc.). The concern for public health has led to the concept of "multi-barriers", essential to the production of ultra-pure water: each type of pollutant is targeted by different treatment techniques, which are carried out in succession.

The main technical challenges for the successful development of wastewater reuse projects are as follows:

1) The assurance of high operational reliability, not only of treatment facilities, but also of storage reservoirs and distribution networks to guarantee water quality at the point of use. High level of sample conformity is required for all the type of wastewater reuse to minimise health risks and bacterial regrowth. This essential requirement should be take into account for the choice and design of treatment processes.
2) The improvement of treatment process design and integration to meet specific water quality requirements. Available and emerging technologies have to be considered to propose the most appropriate solution for given socio-economic local conditions. Improvements are needed with respect to the economic efficiency and minimisation of by-products. Innovation should be promoted to identify new combination of treatments, including the emerging advanced technologies, with respect to increase the reliability of operation, salt removal and disinfection efficiency. Finally, satellite treatment facilities should be considered to improve water quality at minimal costs.
3) The enhancement of water quality control to demonstrate the compliance of recycled water with existing standards. Rational monitoring programs should be developed, as well as standardised simple and low cost analytical tools for effective monitoring of pathogens. Advanced analytical tools, developed for drinking water monitoring would be applied to determine the occurrence of organic micropollutants and emerging pollutants (endocrine disrupters, drugs, etc). New research is needed to assess health risks.
4) The development of best practices for wastewater reuse to guarantee public health safety, decrease water losses and improve the economic efficiency.

The cost of recycled water usually includes only the marginal cost of additional treatment, storage and distribution, excluding the cost of wastewater collection and treatment. The distribution of capital and O&M costs varies from one project to another with a high influence of local constraints: price of the building site, distance between the production site and the consumers, need to install a dual distribution system or retrofitting. The latter two constraints are important as in many projects; the main capital investment concerns the distribution system.

Concerning the specific treatment requirements, a high rate of removal of suspended solids is essential for greater effectiveness of subsequent processes. Particles are particularly troublesome for the disinfection of pathogens, which cling to solid matter, and they are more resistant against the disinfection agents' action. For the safe reuse of wastewater containing carbon and nitrogen pollutants as fertiliser for the purpose of irrigation, an effective particle removal and disinfection are necessary. Such an ambitious objective can be achieved using new advanced treatment lines. In almost all cases, secondary treatment is required to guarantee the reliability and effectiveness of the disinfection step. In this context, the choice of the biological treatment plays also a very important role. Extended aeration, for example, produces easily-disinfected effluents that high rate activated sludge. Membrane bioreactors appear as a very promising emerging technology, producing high quality and fully disinfected effluent. Natural low-tech processes can be also used for small communities or as polishing step and storage reservoirs of previously treated effluents with intensive biological processes. Significant progress has been made in the development and cost optimisation of advanced disinfection technologies as UV irradiation, ozonation, and membrane treatment (microfiltration, ultrafiltration, nanofiltration and reverse osmosis). However, future studies are necessary to improve process operation and cost, as well as to identify new more efficient treatment lines for the various reuse purposes.

The water quality issues have a great impact on water reuse project realisation because of public perception, liability and public health concerns. Both conservative wastewater reuse standards and inadequately low legislative requirements can affect wastewater reuse development. The adoption of guidelines that consider recent advances in scientific research, rather than conservative standards, would consider the cultural and social habits, existing infrastructure and local conditions. Moreover, the development, application and enforcement of best reuse practices, could be the critical step for the rational use of recycled water and successful health and environment protection.

In some cases and countries, wastewater reuse quality issues, in particular for potable reuse purposes, become a major national problem and are subject to controversy. However, unplanned indirect potable reuse occurs in numerous European countries and regions in the United States, with less oversight whenever discharged wastewater quality is subsequently lower and the wastewater percentage is higher. Moreover, in numerous emerging countries, natural resources used for water supply are heavily polluted with raw untreated wastewater. The rational solution for wastewater reuse for augmentation of potable supply is to apply appropriate treatment lines and appropriate monitoring procedures, developed and applied for water resources and drinking water monitoring. Among the most important parameters are pathogens, trace organics and endocrine disrupters. For agricultural and landscape irrigation, it is important to take into account the salinity, boron and sodium-adsorption ratio.

PUBLIC ACCEPTANCE AND EDUCATION

The development of sustainable water recycling schemes must include an understanding of the social and cultural aspects of water reuse. The long-term objective is to promote expertise in closure of local scale water cycles within internationally different economic, social and cultural contexts.

To accomplish this, it is necessary to enlarge traditional design and management activities to:

1) Assessment of cross-cultural barriers and facilitators of water recycling schemes.
2) Information of the public by the organisation of forums with local agencies, municipalities, water utilities, legislative officers from the earliest stage of development of wastewater reuse programs. Develop description of the proposed technologies, their performances, risks associated, costs and benefits to catchment scale water conservation and sustainable development.
3) Development of public education programs (newsletters, school education programs, open houses and tours, meetings with stakeholders). The public's knowledge and understanding of the safety and appropriate applicability of recycled water is a key component of any successful water reclamation program.
4) Establishment of new marketing approaches to consider recycled water as a new product for sale.

The demonstration of the social value of wastewater reuse is important challenge for the worldwide development of wastewater reuse projects for all countries:
- The main aims of wastewater reuse for developing countries are to ensure a vital, in same cases, alternative resource for food production, as well as health and environmental protection. The last point is important. Poverty contributes in high level to environmental degradation. In poverty-stricken areas survival prevails over environment protection. The impoverished become the first victims of environmental degradation.
- For developed countries, wastewater reuse limits the loss of capital required for mobilisation of new water resources, including desalination, as well as for wastewater treatment, which is needed in all cases for social and environmental reasons.

One of the most important challenges is to understand the cultural barriers to wastewater reuse. Controversial opinions exist on the impact of local culture and religion. For example, some authors state that taboos, local habits and customs make Islamic people very sceptical about reusing wastewater. The Islamic beliefs two groups of water, clean and dirty, not determined by its origin, but by the water quality, including colour, taste, smell and pollutant content. Consequently, dirty water can be transformed to clean water, whereas polluted natural resources can be considered as dirty water.

The real problems rise from the political interpretation of water quality issues. According to several recent water quality studies, the recycled water produced in the USA from urban secondary effluents is better in terms of water quality, compared to a number of natural surface waters. Moreover, the epidemiological studies indicated no microbiological or toxicological risks in recycling treated wastewaters. Despite the rigorous scientific arguments, two new projects under development in Tampa, Florida and San Diego, California, have been stopped because the strong opposition of politicians. The statement used "from toilet to tap" was very efficient, without the consideration of scientific results or cost/environment analysis.

Marketing is another keys to the success of water reuse projects. Recycled water, after appropriate treatment is a new marketable product. To help the development of recycled water marketing strategies, the first step is to review the existing state-of-the-art terminology. The definitions of wastewater reuse, wastewater reclamation and wastewater recycling cause real confusion in potential consumers. Well-treated wastewater, with respect to the beneficial reuse, should no longer be considered as wastewater but as a new alternative water resource. This new resource could be named recycled water, which is safer and cleanest than numerous contaminated natural water resources. Finally, the successful development of multi-quality reuse practices requires a pro-active marketing approach to convince potential consumers for a voluntary participation. Compared to the existing situation in water supply and wastewater treatment, the marketing challenges in the wastewater reuse field call for the for application of the latest innovative techniques in this area.

INSTITUTIONAL CHALLENGES

The institutional factors govern the implementation time and quality of a project, not its success or failure. In the case of complex administrative organisation, the development of wastewater reuse could be restricted by confliction interest between organisations; such as the department of environment and the department of agriculture or between local and national governments. Therefore, an administrative reorganisation may be necessary to guarantee the development of wastewater reuse as a general water management scheme.

The successful management of the water cycle, including water reuse, can be favoured by the nomination of an integrated agency to manage and promote the development of integrated resource management strategies with water reuse with maximum economic and environmental benefits. Where several agencies are in charge of the water resources management, water supply and wastewater management, the key to success is communication between those agencies that may be impacted by the reuse project, either directly or indirectly.

CONCLUSIONS

Water recycling is becoming the engine of the global water management. The numerous state-of-the-art technologies enable wastewater to become a resource comparable with water from the natural environment by applying reliable effective treatments, which can be easily adapted to the specific needs of different uses. The inclusion of such systems into the long and medium-term water planning is an essential condition for the balance of the natural cycle and resource conservation for the next millennium. However, the successful implementation of wastewater reuse systems requires the development of new concepts, tools and approaches for public education and marketing of recycled water as a new product, as well as institutional reorganization and development of new policy and regulations.