RECYCLE AND REUSE OF DOMESTIC WASTEWATER

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Summary

Reuse of wastewater for domestic and agricultural purposes has been occurring since historical times. However, planned reuse is gained importance only two or three decades ago, as the demands for water dramatically increased due to technological advancement, population growth, and urbanization, which put great stress on the natural water cycle. Reuse of wastewater for water-demanding activities, which, so far consumed limited freshwater resources is, in effect, imitating the natural water cycle through engineered processes. Several pioneering studies have provided the technological confidence for the safe reuse of reclaimed water for beneficial uses. While initial emphasis was mainly on reuse for agricultural and non-potable reuses, the recent trends prove that there are direct reuse opportunities to applications closer to the point of generation. There are also many projects that have proved to be successful for indirect or direct potable reuse. All the case studies presented in this article point towards the potential wastewater has to serve as a viable alternative source of water, in future.

1. Introduction

The total supply of freshwater on earth far exceeds human demand. Hydrologists estimated that if all the water available on the planet—from oceans, lakes and rivers, the atmosphere, underground aquifers, and in glaciers and snow—could be spread over the surface, the earth would be flooded to an overall depth of some three kilometers. About 97 percent of this water is in the oceans, and out of the remaining three percent, only about one-hundredth is the accessible freshwater that can be used for human demand. If this available water could be evenly distributed, still it is enough to support a population about ten times larger than today. The foremost use of water by humans is for the biological survival. However, water need for the biological survival is not the only issue being discussed in the world today. Because, apart from drinking, water is required also for household needs such as cooking, washing, and is vital for our development needs, such as for agriculture and industry.

Unfortunately, the available freshwater supplies are not evenly distributed in time and space. Historically, water management has focused on building dams, reservoirs, and diversion canals etc., to make available water wherever needed, and in whatever amount desired. Soaring demands due to rapidly expanding population, industrial expansion, and the need to expand irrigated agriculture, were met by ever larger dams and diversion projects. Dams, river diversions, and irrigation schemes affected both water quality and quantity.

Demands on water resources for household, commercial, industrial, and agricultural purposes are increasing greatly. The world population will have grown 1.5 times over the second half of the twenty-first century, but the worldwide water usage has been growing at more than three times the population growth. In most countries human populations are growing while water availability is not. What is available for use, on a per capita basis, therefore, is falling. Out of 100 countries surveyed by the World Resources Institute in 1986, more than half of them were assessed to have low to very low water availability, and quality of water has been the key issue for the low water availability. Given the rapid spread of water pollution and the growing concern about water availability, the links between quantity and quality of water supplies have become more apparent. In many parts of the world, there is already a widespread scarcity, gradual destruction and increased pollution of freshwater resources.

In industrialized countries, widespread shortage of water is caused due to contamination of ground and surface water by industrial effluents, and agricultural chemicals. In many developing countries, industrial pollution is less common, though they are severe near large urban centers. However, untreated sewage poses acute water pollution problems that causes low water availability. Development of human societies is heavily dependent upon availability of water with suitable quality and in adequate quantities, for a variety of uses ranging from domestic to industrial supplies. An estimate infers that every year, the wastewater discharges from domestic, industrial and agricultural practices pollute more than two-thirds of total available run-off through rainfall, thereby, what can be called a “man-made water shortages.” Thus, in spite of seeming abundance, water scarcity is endemic in most parts of the world. It is because of these concerns, the Agenda 21 adopted by the United Nations Conference on Environment and Development, popularly known as the “Earth Summit” of Rio de Janeiro, 1992, identified protection and management of freshwater resources from contamination as one of the priority issue, that has to be urgently dealt with to achieve global environmentally sustainable development.

The need for increased water requirement for the growing population in the new century is generally assumed, without considering whether available water resources could meet these needs in a sustainable manner. The question about from where the extra water is to come, has led to a scrutiny of present water use strategies. A second look at strategies has thrown a picture of making rational use of already available water, which if used sensibly, there could be enough water for all. The new look invariably points out at recycle and reuse of wastewater that is being increasingly generated due to rapid growth of population and related developmental activities, including agriculture and industrial productions.

2. History of Wastewater Reuse

The term "wastewater" properly means any water that is no longer wanted, as no further benefits can be derived out of it. About 99 percent of wastewater *is* water, and only one percent is solid wastes. An understanding of its potential for reuse to overcome shortage of freshwater existed in Minoan civilization in ancient Greece, where indications for utilization of wastewater for agricultural irrigation dates back to 5000 years. Sewage farm practices have been recorded in Germany and UK since 16^{th} and 18^{th} centuries, respectively. Irrigation with sewage and other wastewaters has a long history also in China and India. In the more recent history, the introduction of waterborne sewage collection systems during the 19^{th} century, for discharge of wastewater into surface water bodies led to indirect use of sewage and other wastewaters as unintentional potable water supplies. Such unplanned water reuse coupled with inadequate water and wastewater treatment, resulted in catastrophic epidemics of waterborne diseases during 1840s and 50s. However, when the water supply links with these diseases became clear, engineering solutions were implemented that include the development of alternative water sources using reservoirs and aqueduct systems, relocation of water intakes, and water and wastewater treatment systems. Controlled wastewater irrigation has been practiced in sewage farms many countries in Europe, America and Australia since the turn of the current century.

For the last three decades or so, the benefits of promoting wastewater reuse as a means of supplementing water resources and avoidance of environmental degradation have been recognized by national governments. The value of wastewater is becoming increasingly understood in arid and semi-arid countries and many countries are now looking forward to ways of improving and expanding wastewater reuse practices. Research scientists, aware of both benefits and hazards, are evaluating it as one of the options for future water demands.

3. Motivational Factors for Recycling/Reuse

Major among the motivational factors for wastewater recycle/reuse are:

- opportunities to augment limited primary water sources;
- prevention of excessive diversion of water from alternative uses, including the natural environment;
- possibilities to manage in-situ water sources;
- minimization of infrastructure costs, including total treatment and discharge costs;
- reduction and elimination of discharges of wastewater (treated or untreated) into receiving environment;

- scope to overcome political, community and institutional constraints.

Reuse of wastewater can be a supplementary source to existing water sources, especially in arid/semi-arid climatic regions. Most large-scale reuse schemes are in Israel, South Africa, and arid areas of USA, where alternative sources of water are limited. Even in regions where rainfall is adequate, because of its spatial and temporal variability, water shortages are created. For example, Florida, USA is not a dry area, has limited options for water storage, and suffers from water shortages during dry spells. For this reason wastewater reuse schemes form an important supplement to the water resource of this region.

Costs associated with water supply or wastewater disposal may also make reuse of wastewater an attractive option. Positive influences on treatment costs of wastewater and water supplies, and scopes for reduction in costs of headworks and distribution systems, for both water supply and wastewater systems has been the motivation behind many reuse schemes in countries like Japan.

Reuse is frequently practiced as a method of water resources management. For example, depleted aquifers may be “topped-up” by injection of highly treated water, thus restoring aquifer yields or preventing saltwater intrusion (in coastal zones).

Avoidance of environmental problems arising due to discharge of treated/untreated wastewater to the environment is another factor that encourages reuse. While the nutrients in wastewater can assist plant growth when reused for irrigation, their disposal, in extreme cases, is detrimental to ecosystems of the receiving environment. In addition, there may be concerns about the levels of other toxic pollutants in wastewater.

Concern about water supply or environmental pollution may emerge as a political or institutional issue. Community concern about the quality of wastewater disposed to sensitive environments may lead to political pressures on the water industry to treat wastewater to a higher level before discharge, that can be avoided through reuse of wastewater. Institutional structures may also provide incentives for reuse. Because responsibility for different parts of water use and disposal system may rest with different organizations, a water utility may also be faced with standards of service set in agreements with other industry bodies.

4. Quality Issues of Wastewater Reuse/Recycling

Despite a long history of wastewater reuse in many parts of the world, the question of safety of wastewater reuse still remains an enigma mainly because of the quality of reuse water. There always have been controversies among the researchers and proponents of extensive wastewater reuse, on the quality the wastewater is to meet. In general, public health concern is the major issue in any type of reuse of wastewater, be it for irrigation or non-irrigation utilization, especially *long term impact of reuse practices*. It is difficult to delineate acceptable health risks and is a matter that is still hotly debated.

Issues other than quality of reuse water includes, socioeconomic considerations, and hydro-geologic conditions. The socioeconomic considerations include community perceptions, and the costs of reuse systems. Wide community level surveys in various States of Australia during early 1990s indicated that in general, public is not averse to the concept of wastewater recycling within the community. In one of such surveys, however, less than 15% readily agreed for potable reuse. While non-potable reuse options was a technically accepted option, concerns about possible health risks were frequently raised by the public. Documented public health investigations available in USA is given in US Environmental Protection Agency Guidelines which considered that epidemiological studies of exposed populations at water reuse sites are of limited value, because of the mobility of the population, small sizes of such study populations, and difficulties in determining the actual level of exposure of each studied individual. Despite the limitations of epidemiological investigations, the wastewater reuse in the US has not been implicated as the cause of any infectious disease outbreaks. A more specific study of the city of St. Petersburg, Florida to estimate the potential risk to the exposed population concluded that:

- there is no evidence of increased enteric diseases in urban regions housing areas irrigated with treated reclaimed wastewater, and
- there is no evidence of significant risks of viral or microbial diseases as a result of exposure to effluent aerosols from spray irrigation with reclaimed water.

However, the study recommended that adequate treatment schemes must always be designed to eliminate, or at least minimize the potential risks of disease transmission.

The economic considerations are necessary because, when “first-hand” water is available at a cheaper price, it may not be worthwhile to reuse wastewater, unless there are other special conditions. Consideration of hydro-geologic conditions helps to compare the reuse water quality and the quality of alternative sources intended for the same kind of use.

Almost all the guidelines and standards for wastewater reuse deal mainly with the reuse of wastewater for irrigation purpose. It is mainly because irrigation is the highest water consuming activity in any country, and hence is the first option considered in any reuse planning. For example, 90 percent of available water supply in the Indian subcontinent, and a staggering 98 percent in Egypt, is used in irrigation. Though there are no generalized guidelines for reuse water quality for other options, in countries like Japan, where domestic reuse also is widely practiced, there are standards for such reuse.

4.1 Pathogen Survival

Public health concerns center around pathogenic organisms that are or could be present in wastewater in great variety. Survival of pathogens in wastewater and in environmental conditions other than their host organisms (mainly humans) is highly variable. Table 1 presents the survival periods of various types of pathogenic organisms under various conditions.

Type of pathogen	**Survival time in days**			
	In feces and sludge	**In sewage and freshwater**	**In soil**	**On crops**
1. Viruses				
Enteroviruses	<100 (<20)	<120 (<50)	<100 (<30)	<60 (<15)
2. Bacteria				
Fecal coliforms	<90 (<50)	<60 (<30)	<70 (<20)	<30 (<15)
Salmonella spp.	<60 (<30)	<60 (<30)	<70 (<20)	<30 (<15)
Shigella spp.	<30 (<10)	<30 (<10)	-	<10 (<5)
Vibrio cholerae	<30 (<5)	<30 (<10)	<20 (<10)	<5 (<2)
3. Protozoa				
Entamoeba-hystolytica cysts	<30 (<15)	<30 (<15)	<20 (<10)	<10 (<2)
4. Helminths				
Ascaris-lumbricoides eggs	many months	many months	many months	<60 (<30)

Figures in bracket shows the normal survival time.
Source: Feachem R. G., Bradley D. J., Garelick H. and Mara D. D. (1983). World sanitation and disease: health aspects of excreta and wastewater management by Bank Studies. In *Water Supply Sanitation Vol. 3* Chichester, UK: John Wiley & Sons

Table 1. Survival of pathogens

While emphasizing the need to assess health hazards of wastewater reuse and the importance of various routes of transmission, from direct contact, through food or air, to indirect contact such as in recreational use, there also is a need to recognize the existence of many successive barriers. The barriers include the level of wastewater treatment previously applied leading to settling, adsorption, desiccation of pathogens, as well as soil moisture, temperature, UV irradiation due to sunlight, pH, antibiotics, toxic substances, biological competition, available nutrient and organic matter, leading to pathogen die-away and/or removal from the wastewater source until final ingestion by humans to result in infection. The method and time of application of wastewater and the soil type will also have an influence. Extensive and rational epidemiological studies have led to a consensus view that the actual risk associated with irrigation with treated wastewater is much lower than previously estimated, and the early microbiological standards were unjustifiably restrictive for wastewater reuse.

Another aspect of indirect pathogen contamination due to wastewater reuse has been the contamination of soil and subsequent entry of pathogen into groundwater. The principal methods of pathogen transport in soils include movement downwards with infiltration water, movement with surface runoff and transport on sediments and waste particles. Long-term research studies carried out to understand this effect have concluded that no soil or groundwater quality degradation occurred due to prolonged wastewater application. One of the important processes that controls the contamination of groundwater is the adsorption or retention of organisms on soil particles. Another process assisting in the removal of bacteria and viruses from water percolating through the soil is filtration.

4.2 Other Water Quality Parameters

Other water quality parameters of concern in wastewater reuse have been toxic metal accumulation and salinity of wastewater. The availability of heavy metals to plants, their uptake and their accumulation depend on a number of soil, plant and other factors. The soil factors include, soil pH, organic matter content, cation exchange capacity, moisture, temperature and evaporation. Major plant factors are the species and variety, plant parts used for consumption, plant age and seasonal effects.

Dissolved salts causing salinity in wastewater exert an osmotic effect on plant growth. An increase in osmotic pressure of the soil solution increases the amount of energy which the plant must expend to take up water from the soil. As a result, respiration is increased and the growth and yield of plants decline. However, it has been found that not all plant species are susceptible. A wide variety of crops normally are tolerant to salinity. Salinity also affects the soil properties such as dispersion of particles, stability of aggregates, soil structure and permeability.

4.3 Effluent Quality Standards

Considering the wide-ranging potential for wastewater reuse, it may be difficult to set some common quality standards for all types of reuses. Many countries in the world do not have detailed standards or guidelines for recycle and reuse of wastewater. For many countries in Europe, either the guidelines of World Health Organization (WHO) or the US Environmental Protection Agency (USEPA) standards form the basis for any decision or for granting permission to any kind of reuse. Countries like old USSR, Israel and Tunisia have developed their own standards for reuse. Standards or guidelines for other possible reuses such as groundwater recharge, industrial uses etc., are not common, mainly because such types of reuses are not widespread.

First water quality criteria for reuse of wastewater in irrigation were set in 1933, by the California State Health Department. These standards are for microbiological parameters that indicate the presence of pathogenic organisms in wastewater. In 1971, the WHO meeting of experts on reuse of wastewater recognized that mere presence of pathogens is not sufficient to declare water for reuse as unsafe, and considered that the California standards were overly strict and hindered widespread reuse practice, and recommended a much relaxed microbiological standard for wastewater irrigation. Table 2 presents the microbiological quality guidelines for wastewater reuse in agriculture, recommended by WHO.

Reuse condition	**Exposed group**	**Intestinal nematodes***	**Fecal coliforms+**	**Wastewater treatment expected to achieve the quality**
Category A:	Workers,	≤ 1	≤ 1000	A series of

Irrigation of crops likely to be eaten uncooked, sports fields, public parks	consumers, public			stabilization ponds designed to achieve the microbiological quality indicated or equivalent treatment.
Category B: Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees++	Workers	≤ 1	Not applicable	Retention in stabilization ponds for 8-10 days or equivalent helminth and fecal coliform removal
Category C: Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but no less than primary sedimentation.

* Arithmetic mean no. of eggs per 100 ml
+ Geometric mean no. per 100 ml
++ In case of fruit trees, irrigation should cease 2 weeks before fruit is picked
Source: *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture.* Technical report series No. 778, World Health Organization, Geneva, 1989.

Table 2. WHO microbiological quality guidelines for wastewater reuse in agriculture

Standards for other polluting parameters are intended to prevent pollutant inputs becoming harmful to consumers of the harvested food, and to the soil. If pollutants are allowed to accumulate in the soil, its potential use, over the long term, may become limited. By regulating land application, accumulation of pollutants in the wastewater receiving soil can be prevented. However, it is often argued that reuse regulations based on stringent pollutant loading limits, tend to discourage the land application option. Moreover, such limits do not consider the capacity of soils to attenuate pollutants. Through proper management of land applications, the agronomic benefits of wastewater can be realized, and accumulation of pollutants in the soil can be controlled not to reach harmful levels. A comparison of water quality standards for physico-chemical, and toxic polluting parameters for irrigation reuse of wastewater in some of the countries of the world is presented in Appendix I.

5. Types of Wastewater Reuse

Wastewater can be recycled/reused as a source of water for a multitude of water-demanding activities such as agriculture, aquifer recharge, aquaculture, fire fighting, flushing of toilets, snow melting, industrial cooling, parks and golf course watering, formation of wetlands for wildlife habitats, recreational impoundments, and essentially for several other non-potable requirements. Potential reuses of wastewater depends on the hydraulic and biochemical characteristics of wastewater, which determine the methods and degree of treatment required. While agricultural irrigation reuses, in general, require lower quality levels of treatment, domestic reuse options (direct or indirect potable and non-potable) reuses need the highest treatment level. Level of treatment for other reuse options lie between these two extremes.

5.1 Reuse for Irrigation

Agricultural irrigation has, by far, been the largest reported reuse of wastewater. About 41 percent of recycled water in Japan, 60% in California, USA, and 15% in Tunisia are used for this purpose. In developing countries, application on land has always been the predominant means of disposing municipal wastewater as well as meeting irrigation needs. In China for example, at least 1.33 million hectares of agricultural land are irrigated with untreated or partially treated wastewaters from cities. In Mexico City, Mexico, more than 70 000 hectares of cropland outside the city are irrigated with reclaimed wastewater. Irrigation has the advantage of "closing-the-loop" combination of waste disposal and water supply. Irrigation reuse is also more advantageous, because of the possibility of decreasing the level of purification, and hence the savings in treatment costs, thanks to the role of soil and crops as biological treatment facilities. As the water supply requirements of large metropolis are growing, the option of reuse of wastewater for domestic purposes is increasingly being considered. Judging from international experience, there is potential for reuse at all system scales, from household level to the large irrigation schemes. Reuse has advantages as well as disadvantages at each level. The choice is conventionally technical and economic one, though some view it as important that the community as a whole should become more involved in the working of reuse systems.

Irrigation reuse of wastewater can be for application on:

(i) agricultural crops, woodlots and pastures, or
(ii) landscape and recreational areas.

The choice of type of irrigation application generally depends upon the location and quantity of wastewater available for reuse.

5.1.1 Irrigation of Agricultural Crops

As discussed earlier, the oldest and largest reuse of wastewater is for irrigation of agricultural crops. Potential constraints in this type of application are:

(i) surface and groundwater pollution, if poorly planned and managed;
(ii) marketability of crops and public acceptance;
(iii) effect of water quality on soil, and crops;
(iv) public health concerns related to pathogens.

However, many research studies have proved that in addition to providing a low-cost water source, other side benefits of using wastewater for irrigation include increase in crop yields, decreased reliance on chemical fertilizers, and increased protection against frost damage. Modern reuse for irrigation of agricultural purposes in developed countries were the result of two pioneering studies that were conducted in California during the 1970s and 1980s: The Pomona virus study and the Monterey wastewater reclamation study for agriculture.

The Pomona virus study was conducted in Los Angeles in an effort to determine the degree of treatment necessary to minimize potential transmission of waterborne diseases via surface water. The study concluded that complete virus removal is possible through tertiary treatment of wastewater by either direct filtration or activated carbon followed by adequate disinfection, thus proving the possibility for reclamation of "microbiologically risk free" water from wastewater. These results of this study have opened up the possibilities of wastewater reuse for various applications. Since the virus removal through treatment has been established by Pomona study, investigations of Monterey study concentrated on virus survival on crops and in soils in the field. Based on virological, bacteriological, and chemical results from sampled tissues of vegetables grown using wastewater as irrigant, the study established the safety of this type of reuse. Both studies demonstrated conclusively that even food crops that are consumed uncooked could be successfully irrigated with reclaimed municipal wastewater without adverse environmental or health effects.

In many countries in the Mediterranean region, spanning from Spain to Syria, shortage of water has been the main driving force for wastewater reuse. Wastewater from Tunis, the capital city of Tunisia, has been used to irrigate citrus fruit orchards since the 1960s. From 1989 onwards, secondary treated wastewater has been allowed for growing all types of crops, except vegetables. In countries like Morocco, Jordan, Egypt, Malta, Cyprus, and Spain, several large-scale wastewater irrigation schemes are already in operation or under planning. In Israel, the percentage of wastewater reused for irrigation purposes is highest in the region, at 24.4%, which is expected to be increased to 36% by the year 2010.

In temperate zones of Australia, reclaimed water is being used to irrigate a variety of crops including sugarcane. A recent development is the use of reclaimed water for irrigation of tea-tree plantations, which will produce tea-tree oil as a cash crop. Eucalyptus forestry also is a major reuse option followed in Australia, which provides timber for a number of purposes including pulp wood and fire wood.

Table 3 gives a summary of current regulations for irrigation of agricultural crops.

Country	Main feature	Comments
US EPA	200 FC/100mL + residual chlorine depending on the type of crop.	States treatment methods. Standards for landscape irrigation not stated.
Cyprus	50–100 FC/100mL and 200–1000 FC/100mL, for areas with unlimited	No standards for intestinal nematodes for

	public access, and crop irrigation with limited public access, respectively.	all types of reuse. For industrial crops up to 10 000 FC/100mL allowed with higher BOD and SS limits. No irrigation of vegetables allowed.
France	200–1000 FC/100mL depending on the type of crop.	Exposed groups indicated. To be revised shortly.
Israel	120–250 FC/100mL. Regulations for BOD, SS, DO and residual chlorine.	Wide ranging guidelines according to the type of crop irrigated.
Japan	No detectable coliform bacteria for landscape irrigation. Less than 10/mL for reuse as toilet flush.	Guidelines for crop irrigation not mentioned.
Spain	Less than 1000 FC/100mL and less than 1 nematode per liter.	WHO guidelines are generally encouraged.
Saudi Arabia	2.2–100 and 23–200 FC/100mL for unrestricted and restricted irrigation, respectively. Intestinal nematodes 1 per liter.	Includes limits for various physico-chemical parameters.
Tunisia	Intestinal nematode less than 1 per liter.	No limit for fecal coliforms prescribed. Includes wide range of physico-chemical parameters, irrespective of the type of crops.

Table 3. Current regulations for wastewater reuse for irrigation of agricultural crop—a comparison.

5.1.2 Irrigation of Landscape and Recreational Area

Application of reclaimed wastewater for landscape irrigation includes use in public parks, golf courses, urban green belts, freeway medians, cemeteries, and residential lawns. This type of application is one of the most common application of wastewater reuse worldwide. Examples of such uses can be found in USA, Australia, Japan, Mexico and Saudi Arabia among others. These schemes have been operating successfully in many countries for many years without attracting adverse comments. This type of application has the potential to improve the amenity of the urban environment. However, such schemes must be carefully run to avoid problems with community health. Because the water is used in areas that are open to public, there is potential for human contact, so reuse water must be treated to a high level to avoid risk of spreading diseases. Other potential problems of application for landscape irrigation concern aesthetics such as odor, insects, and problems deriving from build-up of nutrients.

The "water mining" project is an innovative concept followed in Australia, in which wastewater from a main sewer in the reticulated wastewater collection system is diverted to be treated and reclaimed for use in landscape irrigation. The first of such a water mining plant was opened in May 1995 at Southwell Park in Canberra. The plant design focused on health issues, noise and odor control, and preservation of neighborhood amenity.

5.2 Domestic and Industrial Reuse

Reuse of wastewater for purposes other than irrigation may be either for:

- industrial reuse;
- non-potable purposes;
- indirect potable purposes; or
- direct potable purposes.

5.2.1 Industrial Reuse

Industrial reuse of reclaimed wastewater represents major reuse next only to irrigation in both developed and developing countries. Reclaimed wastewater is ideal for many industrial purposes, which do not require water of high quality. Often industries are located near populated area where centralized treatment facilities already generate reclaimed water. Depending on the type of industry, reclaimed water can be utilized for cooling water make-up, boiler feed water, process water etc. Cooling water make-up in a majority of industrial operations represent the single largest water usage. Compared to other purposes such as boiler feed and process water, the water quality requirements for industrial cooling is not generally high. Consequently, cooling water make-up presents a single largest opportunity for reuse. In Australia, considered the "driest continent" on earth, cooling water make up would be attractive from the viewpoint of substantially lessening the demand for potable water by power stations. Operational problems encountered in cooling water recirculation systems are irrespective of the quality of make-up water used. They are scaling, corrosion, biological growth, and fouling.

A major problem associated with reuse of wastewater will be biofilm growth in the recirculation system. Presence of microorganisms (pathogens or otherwise) with nutrients such as nitrogen and phosphorus, in warm and well-aerated conditions, as found in cooling water towers, create ideal environments for biological growth.

A successful example for reuse for industrial cooling exists at Eraring Power Station in New South Wales, Australia. Electrical power generation industries, by the nature of their activities, are normally located close to large urban settlements, where domestic wastewater is generated in large quantities. Since power-generating stations have a huge cooling water requirement, they provide potential reuse locations for reclaimed sewage. Eraring Power Station used 4 million liters/day of potable quality water from a local water supply in the Hunter region of New South Wales. When the continued residential growth in the region necessitated an expansion of potable water infrastructure, many environmental issues were raised about the proposed water source, Lake Macquarie. It was assessed that installation of water intake and construction of pipelines to convey it to water treatment plant would have disturbed environmentally sensitive areas around the lake. Then it was identified that such an expansion could be offset if the Power Station could replace its cooling water requirement with reclaimed water from a nearby sewage treatment plant located at Dora Creek.

Pilot scale feasibility studies carried out in Australia have concluded that it is possible to economically treat the domestic wastewater to achieve adequate quality for reuse as cooling water. Based on the conclusions of the feasibility study, a full-scale treatment plant employing cross-flow membrane microfiltration system was installed. The membrane filtration system could remove all suspended solids, fecal coliforms, and giardia cysts. It could also significantly reduce human enteric viruses such as *reovirus* and *enterovirus*. The water reclamation plant at Eraring Power Station demonstrates the potential for reuse of wastewater in power generation and other industrial manufacturing facilities.

5.2.2 Non-potable Domestic Reuse

Adequately treated wastewater meeting strict quality criteria, can be planned for reuse for many non-potable purposes. Non-potable reuse leads to both a reduction water consumption from other sources, and a reduction in wastewater flow rate. So, non-potable reuse schemes can avoid adverse environmental consequences associated with conventional water sources and wastewater disposal systems. Non-potable domestic reuse can be planned either within single households/building, or on a larger-scale use through a reticulation system meant only for use for non-potable purpose.

Systems for individual households/buildings/facilities. In many parts of the world, it has become apparent that it may not be possible to provide a centralized sewage collection facility for all the households, due to both geographic and economic reasons. Wastewater from individual dwellings and community facilities in such unsewered locations is usually managed by on-site treatment and disposal systems. Although a variety of onsite systems have been used, the most common system consists of a septic tank for the partial treatment of wastewater, and a subsurface disposal field for final treatment and disposal.

By segregating the “gray” sullage from “black” toilet wastes, potential for reuse with minimal treatment within the household enhances manifold. There are several different schemes for reusing gray water at the household levels. In California, systems which use gray water treated to a primary level for subsurface irrigation of gardens, have been in use for many years, and studies have shown no health problems associated with the use. In non-sewered areas of Australia, water scarce conditions in some regions of Victoria have prompted interest in gray water recycling for garden irrigation. Collection and recycling systems for bathroom and laundry water have recently been tested in Victoria. A simple valve arrangement for diversion of laundry gray water for garden watering has been developed. Australian authorities are currently considering the introduction of a comprehensive guidelines for gray water recycling systems in individual households.

Where the gray water is not separated from toilet wastes, improvements in the quality of treated wastewater can be brought about by many alternative systems. One of the alternatives include intermittent and recirculating granular-medium filters. The effluent from a recirculating filter has been found to be of such high quality, it can be used in a variety of applications, including drip irrigation. In Japan, the major in-house gray water reuse system is the hand basin toilets, which uses a hand basin set on the top of the cistern, so the water from hand washing forms part of the refill volume for toilet flushing. Hand basin toilets are reportedly installed in most new houses in Japan.

A large-scale non-potable reuse scheme at the Taronga Zoological Park in Sydney, Australia is operating since 1996. Before the scheme, wastewater and stormwater from the zoo premises were being discharged with less effective treatment into Sydney Harbor. Reports of foul smell and discolored water from the public were common. With the reuse scheme in place, the zoo now treats all wastewater generated, and recycles about 200 kl/day of reclaimed water to hose down animal enclosures, watering the gardens and lawns, flush public toilets and fill ornamental moats.

Large-scale non-potable reuse through a dual reticulation system. A Dual reticulation system is the wastewater reuse concept for urban areas where a centralized sewage collection system is in place, on a large scale. This system supplies treated wastewater to houses, and commercial/official/shopping complexes through a separate water supply network, to be used primarily for toilet flushing, and irrigation of lawns. Thus, households will have two water supply lines, one for potable and human-contact use purposes, and the second for non-potable, non-contact uses such as toilet flushing, use in the yards and gardens etc., hence the name “dual reticulation system.”

Dual reticulation system case studies:

1. USA. The city of Altamonte Springs, near Orlando in Florida, USA has a long established sewage reuse scheme for non-potable residential and other uses, through dual reticulation systems. The incentives to build the reuse scheme came from concerns about maintaining the quality of the lake which received the treated wastewater of the city, and from the need to limit withdrawals of potable water from the Central Florida groundwater aquifer.

Wastewater for reclamation is withdrawn from the isolated sewer lines collecting wastewater predominantly from residential sites. It is low in salinity. The treatment train includes,

(i) primary sedimentation tanks,
(ii) secondary biological treatment including nitrification systems,
(iii) tertiary chemical coagulation, filtration, reaeration and high-level disinfection,
(iv) polishing for dechlorination and pH control.

A comprehensive and continuous process control and a well-equipped laboratory support the treatment system for quality control. Trenchless technology was used to retrofit the city with small-diameter pipes for delivery of reclaimed water. This means that there was no need to excavate streets, pathways.

This scheme serves a population of some 45 000 people, and the reclaimed water is used for irrigation of lawns in industrial, commercial and public buildings (including the grounds of a public hospital), as well as open space irrigation. Some of the reclaimed water is being supplied to office and apartment buildings for toilet flushing, and once-through cooling in industries. The water is also used for water level control in the lake, automobile washing, public fountains and water falls. About 30–40% of the total water use is provided by the dual reticulation system, which produces about 45 Ml per day of reclaimed water. Extensive public consultation combined with a mixture of forceful advocacy on the part of city’s water supply authority has resulted in general public acceptance. The city ordinance was amended to enforce compulsory connection to the reclaimed water distribution network. Initial apprehensions about public health risks proved to be misplaced, as no public health impact had been detected in the first six years of operation from 1989 to 1995.

2. Japan. Japan has a long history of planned wastewater reclamation and reuse, the first of which dates back to 1951, when secondary treated effluent of Mikawashima wastewater treatment plant in Tokyo was experimentally used for paper manufacturing in a paper mill nearby. Today, Japan has well developed policies and programs for wastewater recycle and reuse, to promote water pollution control, environmental protection, and amenities for urban environment. Treated wastewater has also been used for washing passenger trains, and as plant water in solid waste incineration plants. The water reuse projects are favored as they stimulate private sector investment in such works as installing drainage and flush-toilet facilities, thereby creating economic side benefits. The status of wastewater reuse in Tokyo in 1993 was as in Table 4.

Wastewater treatment plant	**Applications**	**Quantity (in 1000 m^3/ year)**
Shibaura	Train washing	111
Sunamachi	Dust control by wetting	6
Morigasaki	Plant water at refuse incineration plant	386
Mikawashima	Industrial water	8835
Ochiai	Toilet flushing	970
Tamagawa-Joryu	Stream augmentation	12370

Source: Maeda M., Nakada K., Kawamoto K., and Ikeda M. (1996). Area-wide use of reclaimed water in Tokyo, Japan. *Journal of Water Science and Technology,* **33**(10–11), 51–57

Table 4. Wastewater reuse in Tokyo in 1993.

Japan has several instances of graywater reuse in high-rise buildings through dual reticulation system. Through various economic incentives, existing and new high rise buildings in Japan are encouraged to have a dual reticulation system. In 1990, about 844 buildings were identified to have wastewater recycling systems. A water recycling project for area-wide non-potable reuse of reclaimed water has been adopted in Shinjuku, a business and commercial center. Shinjuku has been one of the largest urban redevelopment projects in Tokyo, and the water demand for this newly developed business district has been largely coped-up with the supply of reclaimed wastewater through a dual reticulation system.

Secondary treated wastewater forms the influent to the water recycling system. The recycling system consists of rapid sand filters, pumping facilities, force mains, recycling center that house distribution reservoir and distribution pump, and distribution network. The Shinjuku water distribution center is located in the basement of a hotel. Because of its location, noise, odor and other nuisances are strictly controlled. The system supplies reclaimed water to 19 high-rise buildings that house commercial and office premises, up to a daily maximum of 8000 KL, since 1991. The Tokyo Metropolitan Government, in an effort to promote water conservation, and wastewater reclamation, introduced increasing block rate structure of water and waste charges. All new buildings were requested to provide dual system, for the use of reclaimed water. By setting up 20% lower water charge for of reclaimed water, its use has been encouraged.

The Fukuoka city comprise a population of over 1.3 million, and covers an area of about 340 sq.km. Due to the non-availability of stable water source either through large rivers or groundwater, for the domestic and industrial water supply, the Fukuoka City Council started vigorously promoting a water conservation plan since 1979, which included wastewater reclamation and reuse. The city reclaimed water supply amounting to 4500 KL per day in 1995, and is planning to achieve the rate of 8000 KL/day by the end of the century.

3. Australia. Recycling reclaimed water and stormwater for residential non-potable uses has been estimated to have potential to reduce residential water demands by an average of 40—50% in most Australian cities. There are many pilot scale dual reticulation schemes in Australia. Social surveys conducted in Melbourne indicated that people support recycling of bathroom and laundry wastewater. In Western Australia, domestic graywater reuse has been an accepted option for future urban expansions. Commercial scale systems have been installed in Rouse Hill, a suburban area near Sydney, and New Haven in South Australia. The Rouse Hill scheme is Australia's first full-scale application of domestic non-potable reuse through a dual reticulation system.

The decision to include a dual reticulation system was taken after the sewage treatment plant (STP) design for the Rouse Hill Shire Council has been completed. In order to achieve the desirable water quality, and to fulfil the acceptable treatment train recommended in the "Guidelines for urban and residential use of reclaimed water" of the State of New South Wales (NSW), a tertiary treatment train to the completed STP was added. This train included coagulation, flocculation, clarification, filtration, disinfection and pH control. Table 5 summarizes the salient design parameters of the Rouse Hill tertiary treatment plant, and compares them with the requirements of NSW guidelines, and the Californian treatment train adopted in Florida, USA.

Treatment unit	Rouse Hill STP	NSW guidelines	California process (Florida)
Coagulation	1 min. hydraulic retention time (HRT)	Optional	Required if turbidity is more

			than 5 NTU
Flocculation	20min. HRT, 3 stage	Not specified	Not specified
Clarification	2.4 m/hr. peak flow	Not specified	Not specified
Filtration	0.3 m medium depth, 10 m/h filtration rate	0.9 m medium depth, 12 m/h filtration rate	0.9 m medium depth, 12m/h filtration rate
Disinfection	5 mg/l free chlorine, 1 hr. contact time	5 mg/l free chlorine, 1hr. contact time	5 mg/l free chlorine, 2 hr. contact time
pH control	6.5–8.0	6.5–8.0	Not specified

Source: Law I. B. (1996) Rouse Hill—Australia's first full scale domestic non-potable reuse application. *Water Science and Technology,* **33**(10–11), 71–78

Table 5. Tertiary treatment plant criteria for non-potable water reuse.

The reclaimed water is pumped and stored in elevated reservoirs, from where water is distributed by gravity through some 34 km of distribution network. Continuity of supply in the non-potable water supply line is achieved by having each of the reservoirs connected to the potable water supply, via an air gap. The reservoirs are also equipped with facilities for dechlorination using sodium metabisulfite to ensure that residual chlorine at the consumer end does not exceed the maximum allowable limit of 0.5 mg/l. Other salient features of the dual reticulation system are:

- reclaimed water is distributed through non-metallic PVC or reinforced plastic pipes;
- reclaimed water supply fittings are distinguished by different labels and color of surface boxes and indicator plates;
- different sizes for the service mains for potable and non-potable water supply are used: the recycled water line is colored lilac and labeled "Recycled water—Do not drink";
- reclaimed water to the houses is connected to the toilets, which are "dual-flush" type, as well as to an external tap with a removable handle;
- price of reclaimed water is fixed at 20 cents/kl as against 65 cents/kl for potable water.

5.2.3 Indirect Potable Reuse

Indirect potable reuse of treated wastewater may occur unintentionally, when wastewater is disposed into a receiving body of water that is used as a source of potable water supply. It can also be through planned schemes, such as that of Cerro del la Estrella sewage treatment plant in Mexico city. Here, treated wastewater which meets the criteria for potable reuse except for total dissolved solids, is diluted by water from other sources to meet this criteria, and used for potable purposes. Another planned indirect potable reuse can be through groundwater recharge of treated wastewater.

Deliberate (artificial) recharge of groundwater aquifers with treated wastewater can be carried out to achieve one or more of the following objectives:

- as storage during periods of low water demand;
- as an additional treatment method;
- as a measure to improve the depleting groundwater potential; and
- as a measure to improve the overall quality of groundwater by injecting reclaimed water of specific qualities.

Use of treated wastewater for artificial groundwater recharge is increasing as a way to treat and store effluent underground for subsequent recovery and unrestricted reuse. A recent report by the National Academy of Sciences, USA, has given a cautious green signal for potable use of water from aquifers recharged with wastewater. The report suggests that with surface infiltration systems for artificial recharge, considerable quality improvements can be obtained as the water flows through the unsaturated zone to the aquifer, and this soil-aquifer treatment (SAT) reduces pretreatment requirement. However, it cautions that impaired quality waters used to recharge groundwater aquifers must receive a sufficiently high degree of pretreatment (prior to recharge) to minimize the extent of any degradation of groundwater quality, as well as to minimize the need for any extensive post-treatment at the point of recovery. In many arid and semi-arid countries, like Israel and Morocco, SAT is used as an extra advanced wastewater treatment process in order to produce an alternative source of water and is considered as a relatively inexpensive but efficient advanced treatment, because it removes efficiently the parasitic protozoa and helminths, as well as bacteria, mostly by filtration. It is because of this reason that water from polluted natural water (as against treated wastewater) sources also have been artificially recharged to be recovered and reused for potable purposes. In Israel, water from a lake is used for recharge for such purposes.

One of the earliest indirect reuse of treated wastewater can be traced back to a pilot study of 1930s, in the city of Los Angeles. The study reported that secondary treated wastewater treated in a long chain of tertiary treatment processes including super chlorination, ferric chloride coagulation, sedimentation, sand filtration, and activated carbon filtration, has been infiltrated into ground up to 7–5 m above groundwater table in a dry river bed 2–5 km upstream from collection galleries for the municipal water system. In Arizona, USA, many cities and towns recharge their aquifers with urban wastewater to obtain “recharge credits,” which allows them to continue pumping their groundwater wells for municipal water supplies. Recharged water is recovered for use in drinking, irrigation and industrial purposes.

5.2.4 Direct Potable Reuse

Direct potable reuse means adding treated wastewater directly into the normal drinking water distribution system. Though the idea of such a wastewater reuse may be repugnant to many, technologically, direct potable reuse of treated wastewater has been feasible for many years. A classic example of wastewater reuse for direct potable purposes in an emergency happened in 1950s in the town of Chanute, Kansas, USA. The Nesho river in eastern Kansas served as the sole water source of Chanute. Due to continuous drought for five years, surface flow of the river ceased in 1956. After considering all other alternatives, the river was dammed just below the towns sewage outfall, and the treated wastewater was used to fill the potable water intake pool. For five months, the city reused its sewage, circulating it some eight to fifteen times. Thanks to the elaborate sewage treatment as well as for raw water, the bacteriological qualities were met. An epidemiological survey showed fewer cases of stomach and intestinal illness during recycle than in the following winter when Chanute was back to use as river water. In the United States, the Denver Potable Reuse Demonstration Project has operated since 1984. A larger demonstration plant at Daspoort sewage treatment plant, however, did not reuse treated wastewater to supplement drinking water supplies for various reasons.

Case study of Windhoek water reclamation scheme for direct potable reuse. Another famous example widely quoted for direct potable reuse of reclaimed water is the reclamation scheme adopted in Windhoek, capital city of Namibia, which was initiated in 1968. The city of Windhoek, approached the limits of its conventional drinking water sources during the 1960s due to severe water shortage, as groundwater and surface water sources in the vicinity of the city had been fully harnessed. Therefore, in 1968, the city adopted a water reclamation scheme from domestic wastewater to supplement the potable water to the city. The scheme was well publicized and there has been no public opposition. The reclamation scheme was founded on the three basic premises for reclamation to succeed: diversion of industrial and other potentially toxic wastewater from the main wastewater stream, wastewater treatment to produce an effluent of adequate and consistent quality, and effluent treatment to produce acceptable potable water. In addition, it was considered that it is of utmost importance to develop a multi-barrier treatment sequence as a safeguard against pathogens.

The industrial wastewaters were diverted to be treated in separate small treatment plants, and only the industries that do not generate wastewater were allowed in areas were effluents merged with domestic sewage. The system went through a succession of modifications and improvements over the year. The wastewater is treated in two separate, consecutive treatment plants to potable standard. The first is the conventional biological treatment plant (activated sludge process) at Gamams to treat raw wastewater. This wastewater is discharged into a series of maturation ponds, from where the effluent gravitates directly to the water reclamation plant at Goreangab. The water reclamation plant consists of alum coagulation, dissolved air floatation, lime dosing, sedimentation, sand filtration, breakpoint chlorination, activated carbon filtration, and final chlorination.

Up to the present, the reclaimed water is blended in two steps. The first blending step takes place at the Goreangab treatment plant, where the reclaimed water is blended with conventionally treated surface water, which ensures a minimum 1:1 dilution of reclaimed water. The second blending step takes place in the bulk water system of Windhoek, where the blend from Goreangab is mixed with treated water from other sources. It has been estimated that in future, the surface water supply at Goreangab will not have any significant benefit, due to its quality deterioration as well as its reduced contribution to the total flow.

Until 1982, the scheme had research status, and some costs of monitoring were absorbed by the South African Water Research Commission. Since then, the project is considered a normal production facility. To ensure water quality, an independent expert monitoring of system performance, a technical committee representing experts from five independent professional bodies convened three times a year for a detailed review of water quality. This procedure was discontinued since 1988 and replaced by a monitoring system by three independent laboratories. The treated wastewater, before reclamation, is also continuously monitored to ensure a consistent, high quality maturation pond effluent.

The Windhoek experience with wastewater reclamation to potable drinking water standard was an unqualified success during the last twenty-five years, which is of great significance to all arid and semi-arid regions of the world, as it demonstrates that:

- with proper care and diligence, water of acceptable quality can be consistently produced from domestic wastewater,
- if properly informed, consumers will fully accept this perhaps controversial option, wastewater reclamation for direct potable purpose is a practical option, not only for technologically advanced countries, but also for regions with relatively difficult access to advanced technology, management and operating skills.

5.3 Wastewater Sludge Reuse

Wastewater sludge is the solid/semi-solid substance, concentrated form of mainly organic, and some inorganic impurities (pollutants), generated as a result of treatment of wastewater. For any growing modern city, it is necessary to expand its sewage collection system to cater to the needs of the growing urban areas and its population. With the expansion of sewerage system comes the ever-increasing problem of how best the sludge generated in wastewater treatment facilities can be disposed. Disposal methods once used for sludge management, such as ocean disposal, are not environmentally appropriate. Though it is traditionally suggested that the sludge can be applied on land as soil conditioner and as fertilizer, there are many issues involved in handling and transportation, and odor nuisance, which are of concern. Experience in Europe and the USA have shown that land application/reuse of sludge options are the most promising ones that benefit the society. Sludge can be reused to reclaim parched land by application as soil conditioner, and also as a fertilizer in agriculture.

Deteriorated land areas, which cannot support the plant vegetation due to lack of nutrients, soil organic matter, low pH and low water holding capacity, can be reclaimed and improved by the application of sludge. Sewage sludge has a pH buffering capacity resulting from an alkalinity that is beneficial in the reclamation of acidic sites, like acid mine spoils, and acidic coal refuse materials. There are a number of successful land reclamation projects reported from the United States. Operational experience is available for handling systems, application systems, amount required per hectare, and response of various types of vegetation. Sludge with a solid content of 30% or more can be handled with conventional end-loading equipment, and applied with agricultural manure spreaders. Liquid sludge, typically with solid content less than 6%, are managed and handled by normal hydraulic equipment. Agricultural use of sludge matches best with priorities in waste management. Sewage sludge contains nutrients in considerable amounts, which lead to fertilization of soil and organic matters that improve the soil through humic reactions.

Netherlands, Sweden, and Spain in Europe use more than 60% of sludge for agricultural purposes. Denmark, England, and Switzerland use more than 45% for similar purposes. Their experience shows that by following regulations and strict adherence to standards, adverse environmental effects of sludge application for agricultural purpose could be reduced to a minimum, thereby giving confidence to those who rely on them.

New South Wales in Australia has taken a lead role in the adoption of sludge reuse options. Until 1990, over 60% of sludge generated in the wastewater treatment plants was disposed of into the ocean. By 1993, nearly 70% of sludge generated was being recycled, and disposal into the ocean has ceased. Low availability of organic soil conditioners and increasing interest being shown by fertilizer companies to blend organic matter with chemical fertilizers, has created demands for sewage sludge in Australia. To improve the nutrient and other beneficial qualities of sludge, alkaline adjuncts such as lime, cement kiln dust, calcium oxide or calcium carbonate are added. N-Viro soil is one such patented product in Australia, based on addition of quick lime and cement kiln dust with sludge. Composting and vermi-composting of sludge also are carried out in many parts of Australia, to convert into odorless humus material for sale at higher prices.

Sludge has also potential for reuse in manufacture of other beneficial products. Pilot scale work in Canada indicated that sludge can be used to produce a low grade oil by heating sludge to 450°C in the absence of oxygen. The sludge oil has a calorific value of 32 MJ/kg and has been obtained at yields of 13% from anaerobically digested sludge and 46% raw sludge. Manufacturing of bricks using slag and sewage sludge has been developed in many countries. In Australia, a company uses slag ash and sludge together with shale and clay to produce a brick 15% lighter than the regular brick with a superior ratio of strength to firing time.

5.3.1 A Case Study of Sludge Reuse in Japan

Sludge management has been a major concern in major cities of Japan, because of non-availability of land for adoption of traditional methods of sludge disposal. Japan has made pioneering attempts to overcome such inherent problems and could successfully managing it through various reuse options. An insight into how the city of Sapporo, located in the northeastern part of Hokkaido Island, Japan manages its sludge handling could be useful to other cities looking for management and disposal of sludge.

The Hokkaido Island makes up for 22.6% of the total cultivated land in Japan. The general soil is mainly volcanic, lacking in organic material and soil micro-organisms, and hence of poor quality. Heavy clay and composed peat soil are also found in certain parts of the island, which create water stagnation and slow decomposition of organic materials at low temperatures, respectively. Thus, it can be said that Hokkaido has a special soil problem that needs to be dealt with comprehensively so as to make the most out of the potential existing there.

The city of Sapporo generates 465 tons of sludge per day from its 17 pumping stations and 9 sewage treatment plants. The dewatered sludge was originally disposed mainly through landfill and partially through direct application on farmlands. There always is the uncertainty that landfills present for the future. There were also problems of directly using dewatered sludge on land due to handling and also the regulations from the Agricultural Department. Keeping in mind the local conditions, the city decided to mainly adopt composting (Figure 1), and incineration for the management of the sludge. The breakdown of various methods of treatment and disposal of dewatered sludge is given below:

Total sludge generated	169,563 t/yr (100%)

- Disposed through landfills: 27,001 t/yr (15.9%)
- Direct application on land: 2,225 t/yr (1.3%)
- Compost: 25,523 t/yr (15.1%)
- Incineration (Heat Treatment): 44,407 t/yr (26.2%)
- Incineration Centers: 70,407 t/yr (41.5%)

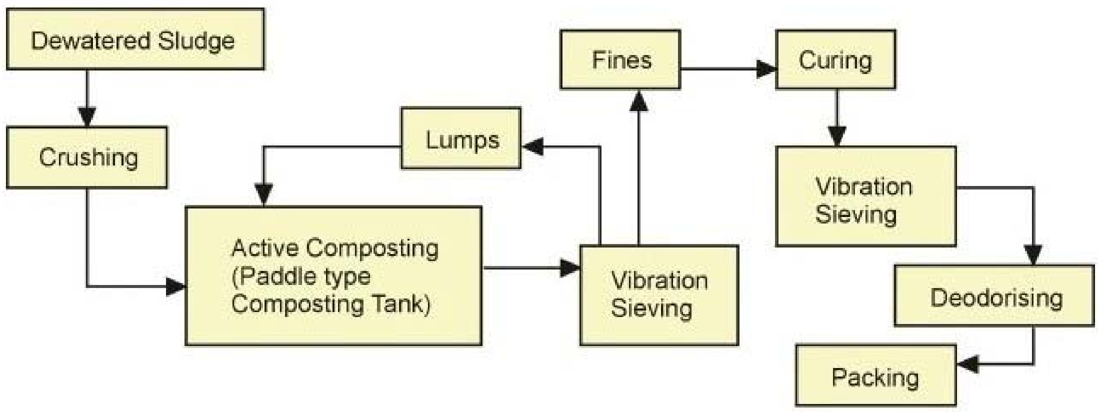

Figure 1. Flow schematic of sludge composting process in Sapporo, Japan

A major problem point in adoption of composting in Sapporo was its low temperature climate throughout the year. This has been overcome by adopting horizontal type paddle method and drum screen method of composting. Both are indoor methods of composting, wherein the process occurs in tanks under controlled conditions. The manufactured compost was sold to the farmers, through agricultural organizations, to golf courses and other public enterprises concerned with green growth. Essentially all the compost produced is sold.

While the compost production has become a sound enterprise gaining good reputation due to its effectiveness and low cost, the users reported some problems. When the compost is being applied through use of spreader machines, the compost clogged the machine nozzles and bridged across the machine hopper. This has been mainly due to the grain size of compost. The granular size of approximately 50% of the compost was less than 1 mm. In order to make compost use more lasting and safer and to improve its handling qualities, the compost is granulated using chemical binders (Figure 2). This has also resulted in deodorization of the compost.

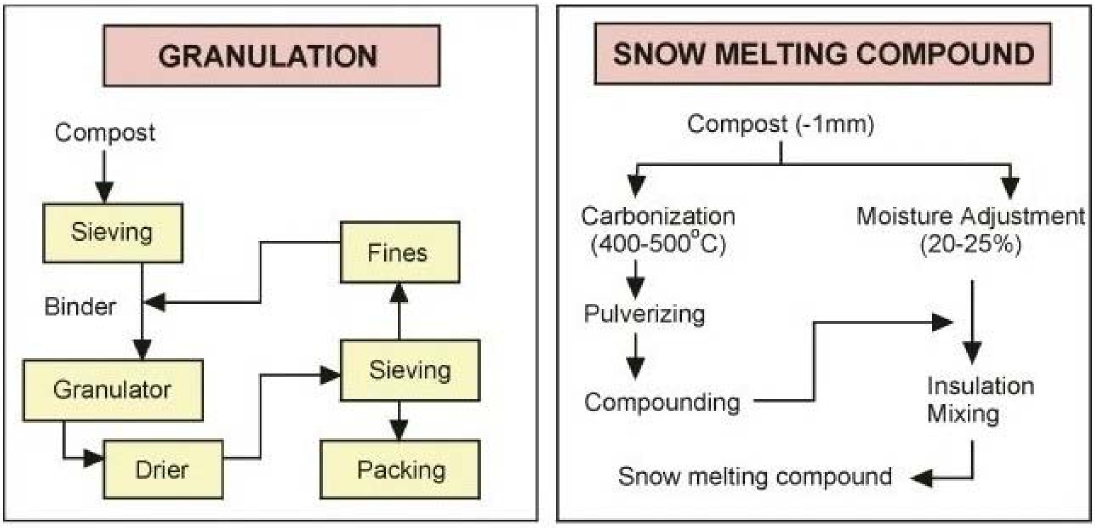

Figure 2. Innovative sludge reuse options developed in Sapporo, Japan

Another important development made in the use of sewage sludge compost is its conversion as a snow melting compound using carbonization process followed by chemical addition (Figure 2). The test application of this product has shown that compared with areas where the compound was not used, the snow melted off of the ground a full week earlier, making it essentially as effective as other melting agents on the market.

The sludge disposal practices and experiences of the city of Yokohama, Japan, is a notable example of sewage sludge treatment and for its utilization as a resource. Until 1975, almost all the sludge generated from the sewage treatment plants of the city of Yokohama was being disposed through landfill after treatment in two centralized sludge treatment centers. The treatment processes adopted are digestion followed by dewatering and/or wet oxidation followed by dewatering. However, disposal of sludge through landfill as a long-term solution is problematic, as it is difficult to secure disposal sites in large cities like Yokohama, and in a land-starved country like Japan. Utilization of the sludge as a resource is the only way to establish a permanent solution to the sludge disposal problems. Therefore, the city has promoted extensive research and development for utilization of treated sludge. The major avenues attempted for utilization of the treated sludge were through use of:

- pelletized dried sludge as fertilizer;
- sludge incineration ash as soil stability improving adjunct, artificial soil for horticulture and brick manufacturing;
- melted sludge slag in paper production and tiles manufacturing.

Details of sludge management for reuse in Yokohama are shown in Figure 3. After commissioning a two-year study in 1971, to assess the fertilizing effects of sludge, the city embarked on development of sludge driers to dry and pellatize digested and dewatered sludge. The energy requirement for this process is planned to derive from the biogas generated during the sludge digestion process.

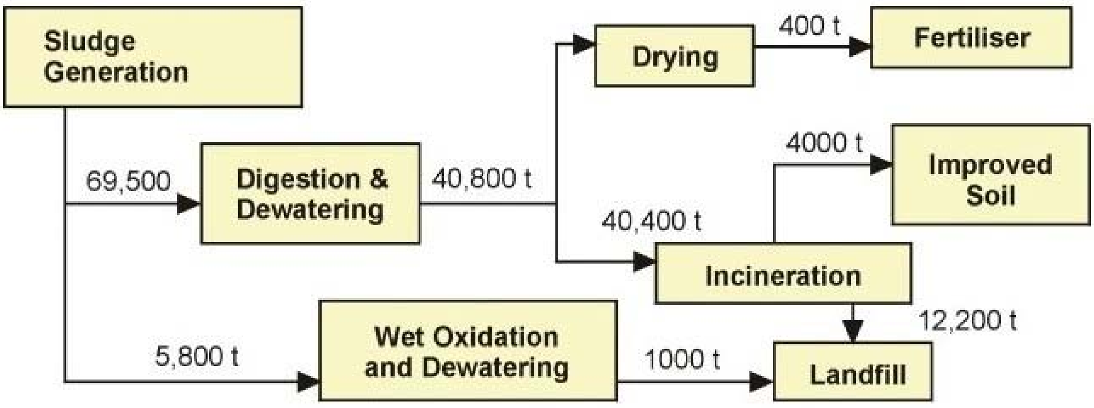

Figure 3. Sludge management for reuse in Yokohama, Japan.

The city has also devised a method for hardening and pelletizing the sludge incineration ash using watery solution of Polyvinyl Alcohol (PVA) as a binder, and ammonium sulfate solution for solidifying the PVA. The product so obtained is named as "Hama Soil" and has good water retention and aeration characteristics with appropriate pH (5.5–6.5) for plant cultivation. Another prospective approach for use of incineration ash is to use it in the manufacturing of bricks by packing a metal mould with the ash, and subjecting it to high pressure of 1 ton/cm^2. Standard testing showed that bricks satisfied standards relating to compressive strength, water absorption rate, chemical resistance and sliding resistance.

In an attempt to diversify the use of sewage sludge in other non-conventional fields, Yokohama city has embarked on the trial production of paper and tiles using melted slag. The melting of sewage sludge is a process whereby the inorganic substances within sludge are melted at a temperature in the range of 1300–1500°C and cooled into a glass type slag. A fibrous form of melted slag, called slag wool, is added to the conventional pulp and the mixture is formed into a paper. The paper manufactured with slag wool having 30% by weight of conventional pulp yielded sufficient strength. Manufacturing of tiles was also carried out using a powdered form of melted slag with conventional base materials, for use as building facades.

6. Future of Water Reuse

As of now, major emphasis of wastewater reuse has been for non-potable applications. In spite of developing sound technological approaches to producing water of any desired quality from reclaimed wastewater, it has generally been too expensive to be taken seriously as a potable supply option. There are several other key issues that include evaluation of health risks associated with trace organic and inorganic contaminants in reclaimed water, application of membrane treatment processes in production of high quality reclaimed water, optimization of treatment trains for wastewater reclamation projects to be cost-effective, that requires additional research and demonstration for progress in reclaimed water reuse applications. There also is a psychological threshold that is keeping us at bay for reuse in potable applications, even when there are no other viable long-term options. If water reuse projects are to succeed, efforts to generate greater community awareness to judge water by its quality and not by its history, and seeking their increased participation in such schemes will also be needed.

Appendix

Quality criteria for irrigation reuse of wastewater for physico—chemical parameters

Parameters	Canada	USA	Taiwan	Hungary	China		Saudi Arabia	Tunisia
	All soils	Sandy soils	All soils	All soils	Paddy crop	Vegetables	All soils	All soils
	1991	1973	1978	1991	Not dated	Not dated	Not dated	Not dated
PH	—	—	6.0–9.0	6.5–8.5	5.5–8.5	5.5—8.5	6.0—8.4	6.5—8.5
Total dissolved solids, mg/L	500—3500	—	—	—	1000–2000	1000—2000	—	—
Suspended solids, mg/L	—	—	100	—	150	200	10	30
Chloride, mg/L	—	—	175	—	250	250	280	2000
Sulfate, mg/L	—		200	—	—	—	—	—
BOD, mg/L	—	—	—	—	80	80	10	—
COD, mg/L	—	—	—	—	200	150	—	90
Aluminum, µg/L	—	5000	5000	5000	—	—	5000	—
Arsenic, µg/L	100	100	1000	200	50	50	100	100
Boron, µg/L	500–600	750	750	700	1000–3000	1000—3000	500	3000
Beryllium, µg/L	100	100	500	100	—	—	100	—
Cadmium, µg/L	10	10	10	20	5	5	10	10
Chromium (total), µg/L	100	100	100	5000	100	100	100	100
Cobalt, µg/L	50	50	50	50	—	—	50	100
Copper, µg/L	200–1000	200	200	2000	1000	1000	400	500
Iron, µg/L	—	—	—	100	—	—	5000	5000
Lead, µg/L	200	5000	100	1000	—	—	100	1000
Manganese, µg/L	—	200	2000	5000	—	—	200	500
Mercury, µg/L	—	—	5	10	1	1	1	1
Molybdenum, µg/L	10–50	10	10	0	—	—	100	—
Nickel, µg/L	200	200	1000	1000	—	—	20	200
Selenium, µg/L	20–50	20	20	—	20	20	20	50
Zinc, µg/L	1000–5000	2000	2000	5000	2000	2000	4000	5000
	—	—	5000	10 000	500	500	500	5000
Cyanide (total), µg/L	—	—	—	8000	—	—	—	—

Oil and grease, µg/L Surfactants, µg/L	—	—	5000	50 000	5000	5000	5000	—

Source: Adopted from Andrew C. C., Albert L. P., Asano T., and Hesphanhol I., “Developing human health related chemical guidelines for reclaimed wastewater irrigation,” *Water Science & Technology*, **33**(10–11), 463–472.

Glossary

Blackwater: Household wastewater containing toilet wastes.

Dual reticulation system: Water distribution system having two separate networks to supply water for potable and non-potable uses respectively.

Graywater: Household wastewater after exclusion of toilet wastes.

Pathogens: Disease-causing microorganisms.

Sludge: The concentrated form organic and inorganic pollutants removed from wastewater as a result of treatment

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Biographical Sketches

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