DECENTRALIZED SYSTEMS FOR WASTEWATER MANAGEMENT AND SUSTAINABLE DEVELOPMENT

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Abstract

The orderly development of urban and near urban areas is dependent on the availability of water. In areas where the available sources of water are limited or are unreliable, it is now recognized that wastewater represents a very reliable water source. In the future, as the demand for fresh water exceeds the supply, and the value of water increases, the role and importance of water reuse will continue to expand. Decentralized wastewater management systems maintain both the solid and liquid fractions of the wastewater near their point of origin. In the future, as long-term strategies are developed to optimize the use of water resources and to protect the environment and sustain development, it is clear that decentralized systems will become an important element of those strategies.

The challenge will be to manage wastewater in a manner that will contribute to the maintenance of public health and a sustainable environment.

1 Introduction

In the new millennium, the effective management of the water resources will become a critical issue, especially as the worlds population continues to increase. To meet the demand for water, wastewater, an undervalued resource, will become a valued source of water. Thus, the importance of wastewater repurification in the field of water resources management is now commonly acknowledged. Similarly, the important role of wastewater repurification and reuse in maintaining a sustainable environment is also gaining wider acceptance. Recognizing the many applications and benefits of wastewater reuse, the purposes of this paper are to: (1) review the impact of population growth on sustainable development, (2) review potential water reuse applications and water quality requirements, (3) review appropriate technologies for wastewater treatment and reuse, (4) consider the type of management structure that will be required in the future, and (5) identify issues that must be resolved to bring about water reuse for sustainable development on a broad scale. The material presented in this paper is meant to serve as an introduction to these topics. Further, because so much has been written about large scale repurification and reuse facilities, the primary focus of this paper is on small and decentralized systems.

2 Population Growth and Sustainable Development

In the United States, and in many other parts of the world, the orderly development of urban and near urban areas is dependent on the availability of water. In many parts of the United States, there have been water shortages of such magnitude that water rationing has been necessary. In areas where the available sources of water are limited or are unreliable, it is now recognized that wastewater represents a very reliable water source. If wastewater from urban and near urban areas were reused locally for a variety of nonpotable uses, the demand on the potable supply would be reduced and population growth could be sustained. As a result, the focus of the field of wastewater management is beginning to change from the construction and management of regional sewerage systems to the construction and management of decentralized wastewater treatment facilities.

Decentralized wastewater management (DWM) may be defined as the collection, treatment, and reuse/disposal of wastewater from individual homes, clusters of homes, or isolated communities, industries, or institutional facilities at or near the point of waste generation (Tchobanoglous, 1995; Crites and Tchobanoglous, 1998). In some areas, the liquid portion could be transported to a central point for further treatment and reuse. Given the increasing demands on freshwater supplies, it is clear that DWM is of great importance in developing long-term strategies for the management of our environment. Therefore, in addition to the implementation of large scale reuse projects, it will become important, in the future, to develop appropriate strategies and operating agencies for the management of localized reuse projects.

3 Wastewater Reuse Opportunities and Requirements

In the planning and implementation of wastewater reuse, the reuse application (see Table 1) will usually govern the wastewater treatment needed, and the degree of reliability required for the treatment processes and operations. Specific reuse categories and treatment technologies that may be applicable will depend on the location and type of wastewater reuse opportunities.

3.1 Reuse Opportunities

Worldwide, the most common use of reclaimed wastewater has been for agricultural and landscape irrigation. Recently, groundwater recharge and indirect and direct potable reuse have received considerable attention in the United States. The repurification project in San Diego, CA, in which it is proposed to blend repurified wastewater with local runoff and imported water in a local water supply storage reservoir, is an example of such a project (WCPH, 1996). For individual decentralized systems, landscape irrigation will continue to be the principal reuse option. For small flows, landscape irrigation and similar applications will continue as the major reuse options. In isolated commercial and industrial facilities, toilet flushing in buildings with dual plumbing systems, and use for water features and landscape irrigation will continue. To maximize the reuse of treated wastewater at or near the point of generation, satellite reclamation plants will continue to increase in number. Satellite plants, either connected to downstream collection systems (as in Los Angeles County for their upstream reclamation plants), or as stand-alone facilities will employ a variety of technologies, depending on the particular reuse opportunities.

3.2 Treatment Requirements

With respect to the required treatment processes, concerns for newly emerging pathogenic organisms which may arise from nonhuman reservoirs (e.g., the protozoan parasites *Cryptosporidium parvum, and Giardia lamblia*) has led to the questioning of the use of traditional indicators that arise primarily from fecal inputs. In a recently completed study, it was concluded that coliform bacteria are adequate indicators for the potential presence of pathogenic bacteria and viruses, but are inadequate as an indicator of waterborne protozoa (Craun et al., 1997). Because *Cryptosporidium* oocysts, *and Giardia* cysts are not as readily inactivated by chlorine and UV disinfection, as are the bacterial surrogates now

TABLE 1 Categories of municipal wastewater reuse and typical applications[1]

Wastewater reuse categories	Typical applications
Agricultural irrigation	Crop irrigation, commercial nurseries.
Landscape irrigation	Parks, school yards, freeway median strips, golf courses, cemeteries, greenbelts, residential.
Industrial recycling and reuse	Cooling water, boiler feed, process water, heavy construction.
Groundwater recharge	Groundwater replenishment, salt water intrusion control, subsidence control.
Recreational/environmental uses	Lakes and ponds, marsh enhancement, streamflow augmentation, fisheries, snowmaking.
Nonpotable urban uses	Toilet flushing, clothes washing, car washing, fire protection, air conditioning, etc.
Potable reuse	Blending highly repurified water with existing water supply, pipe to pipe water supply.

[1] Adapted from Tchobanoglous and Burton (1991).

in use (i.e., *E coli* and total coliform), they must be removed physically to achieve effective disinfection for unrestricted effluent reuse. To remove *Cryptosporidium* oocysts *and Giardia* cysts, some form of membrane filtration will be required, as conventional packed bed filtration is only partially effective in the removal of these resistant forms of the protozoan parasites. Where repurified water is to be reused in applications involving the potential for direct human contact, it is anticipated that treatment with one of the membrane technologies before disinfection with either chlorine, ozone, or UV radiation, or with other appropriate technologies, will be required to reduce the potential risk associated with pathogenic organisms, both known and unknown (Crites and Tchobanoglous, 1998).

4 Appropriate Wastewater Management Technologies

To protect the environment and to maximize reuse opportunities, water quality requirements for treated wastewater for small dischargers are now the same as those for large dischargers. The challenge is to be able to provide the required level of treatment in decentralized systems, subject to serious economic constraints, especially in situations where water is not yet valued economically. Alternative wastewater management technologies for both sewered and unsewered urban and near urban areas are reported in Table 2, with respect to the collection and transport of wastewater, wastewater treatment, and water reuse. The technologies reported in Table 2, are suitable for individual residential systems, for cluster and community systems, as well as for isolated commercial and industrial facilities.

TABLE 2 Technologies used for small and decentralized wastewater management systems

Collection and transport of wastewater	Wastewater treatment and/or containment	Wastewater reuse options
House drains and Building sewers	Primary treatment Septic tank (with effluent, filter vault)	Cooling water
Conventional gravity Sewers	Imhoff tank	Constructed wetlands
Small-diameter sewers Variable- slope Gravity	Disk and spin filters	Crop irrigation
Pressure sewers (with non grinder pumps)	Secondary treatment Aerobic/anaerobic units Aerobic treatment Anaerobic treatment Constructed wetlands Intermittent and recirculating packed-bed filters Membrane bioreactor	Groundwater recharge
Pressure sewers (with Grinder pumps)	Tertiary treatment Carbon adsorption Filtration Membrane filtration Reverse osmosis	Land application Subsurface Drip Shallow trench Shallow sand-filled trench Surface application Drip Spray
Vacuum sewers	Disinfection Chlorine UV radiation Ozone	Landscape and tree watering
Combinations of the Above	Recycle treatment systems (e.g., toilet flushing and landscape watering)	Streamflow augmentation
		Toilet flushing, clothes washing, car washing, etc.
		Combinations of the above

4.1 Wastewater collection

Although the use of gravity-flow sewers for the collection and transport of wastewater from residences and commercial establishments continues to be the accepted norm for sewerage practice in the United States, conventional gravity-flow sewers have proven to be counterproductive as the use of water conservation devices continues to increase. In many areas that are now being developed, the use of conventional gravity-flow sewers may not be economically feasible for reasons of topography, high water table, structurally unstable soils, and rocky conditions. Further, in small unsewered communities, the cost of installing conventional gravity-flow sewers is prohibitive, especially if the density of development is low. To overcome these difficulties, (1) small-diameter variable-slope sewers, (2) pressure sewers (without and with grinder pumps), and (3) vacuum sewers have been developed as alternatives. Because infiltration/inflow is, for all practical purposes, eliminated when alternative wastewater collection systems sewers are used, a variety of alternative treatment processes can be used. For example, the use of recirculating packed-bed filters is usually not feasible if infiltration/inflow cannot be controlled. The potential for contamination from conventional wastewater collection systems through exfiltration is also eliminated through the use of alternative collection systems.

4.2 Wastewater treatment

With respect to wastewater treatment, it is now possible to produce any required effluent water quality. While the cost may be high with some technologies, developments are proceeding at such a rapid pace that it is fair to say that treatment costs will be competitive with centralized facilities or even less, especially so when the cost of wastewater collection is considered.

At this point it is also appropriate to introduce the multiple quality concept (MQC) for the treatment of wastewater. If maximum beneficial reuse is to be made of wastewater, then it is clear that different levels of treatment can be used (see Figure 1). In the applications shown in Figure 1, three different water qualities are used with respect to biochemical oxygen demand (BOD), total suspended solids (TSS), nutrients (N, P, and K), and the presence of microorganisms. Wastewater from an apartment building or commercial facility will be retained in a large water-tight septic tank. A portion of the flow will be used for tree and median strip watering. Because the nutrients in the wastewater are beneficial, the effluent from the septic tank will be applied after it has passed an effluent filter to remove coarse solids larger than about 2 to 3 mm. In a similar manner a portion of the septic tank effluent is passed through a disk or spin filter to remove particles large than 100 μm, before the effluent is applied for drip irrigation, again retaining the nutrients in the wastewater for agronomic use. The remaining septic tank effluent will be treated in a membrane bioreactor and the treated effluent will be used for toilet flushing.

Over the past 10 years, a number of self-contained recycle systems have been developed to take sanitary wastewater from buildings, treat it, and return the bulk of the treated effluent for reuse as toilet and urinal flushing water. Although such processes are expensive, they have been used for office buildings located in unsewered areas and where water for domestic use is in short supply. Moreover, as new water supply sources become increasingly difficult and costly to develop ($400 to $1,200/ac•ft, second quarter 1999), the use of recycle systems is becoming cost-effective. As a result, it is anticipated that the use of such specialized decentralized wastewater management systems will become more prevalent in the future.

4.3 Effluent Reuse

It is important to note that the term "reuse" is used in place of disposal, commonly used in the past for the management of treated effluent. If water reuse is to gain acceptance, the term "disposal" which connotes a problem, must be replaced with the term "reuse" which connotes a resource. For example, given the technology that is now available, it is no longer necessary to look for flat areas for the installation of conventional leachfields for effluent diposal for individual homes. Using pressure dosing with water-well pumps, drip irrigation, and shallow disposal trenches, all available space can be used for the beneficial reuse of treated wastewater.

Unfortunately, conventional effluent disposal trench designs fail to take maximum advantage of the treatment capabilities of the soil because the active part of the trench is typically located below the region of maximum bacterial activity. The use of shallow trenches with no porous medium (see Fig. 2), enhances the treatment of the effluent with respect to the removal of BOD, TSS, nitrogen, and phosphorus. It is also interesting to note that the use of such shallow trenches was recommended in an early Public Health Bulletin in 1915 (Lumsden, Stiles and Freeman, 1915).

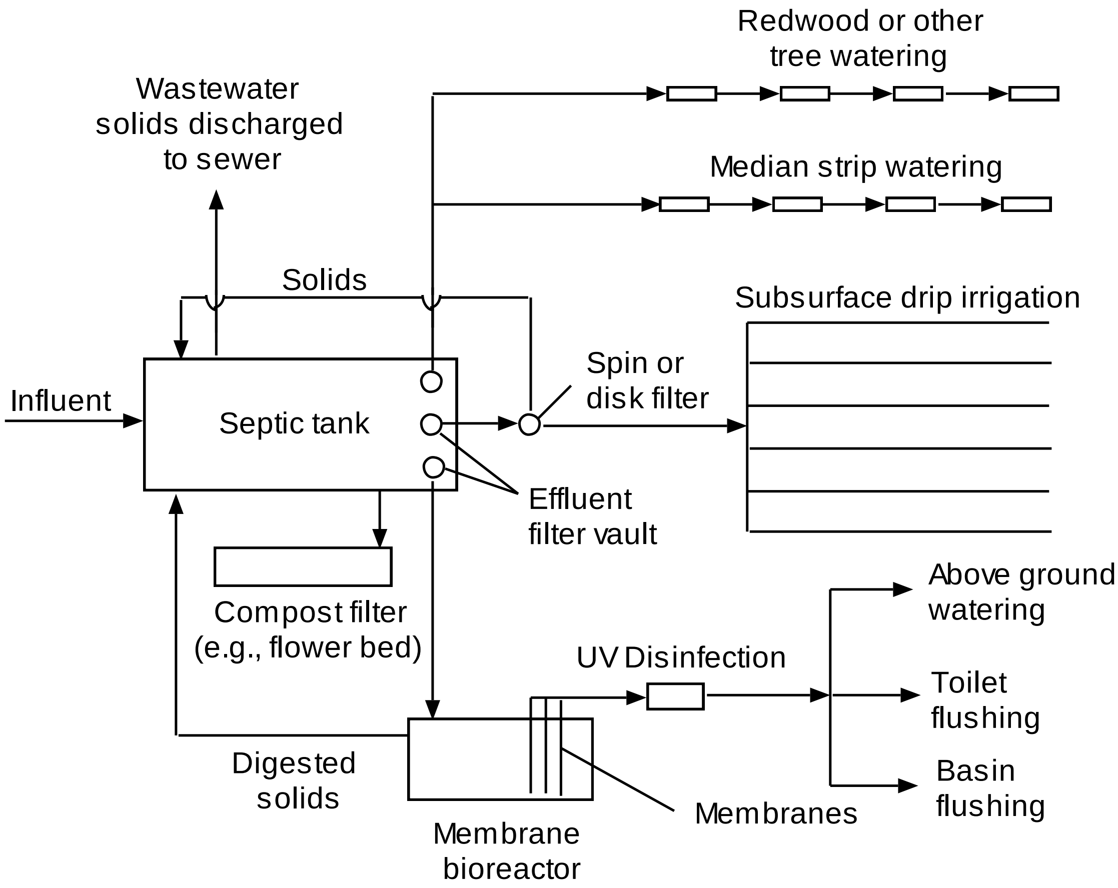
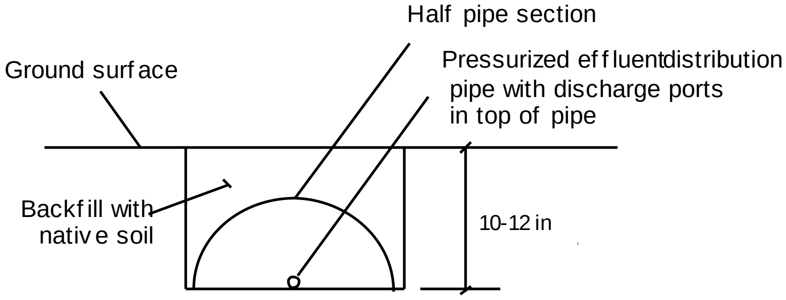


Figure 1
Multiple Quality Concept Treatment And Reuse Scheme For An Apartment Building



(*b*)

Figure 2
Typical shallow soil absorption reuse system

5 Management of Decentralized Systems

Based on development that has occurred in the past five years, it is reasonable to speculate that in the future, the continued use of conventional gravity-flow sewers may be a thing of the past, especially for low density housing areas. Given that it will be possible to treat wastewater locally, the question that is unanswered is what type of management structure should be used? It is clear that new management structures must be developed that will encompass both centralized and decentralized wastewater management systems. The form of these agencies must be conceptualized if maximum benefit is to be derived from localized water reuse.

6 Issues in Water Reuse

The principal issues in implementing greater water reuse are: (1) the economic value of water, (2) technological, (3) regulatory requirements, and (4) social. Each of these issues is considered briefly below.

6.1 Economic value of water

In many parts of the world, water is an under valued resource. Historically, the supplies of water have been plentiful and the price low (Linsky, 1998). As a result, the perception of value for water is lacking. In turn, because of this lack of perceived value, the economics of water reuse are difficult to sell. However, because the worlds population continues to grow (about 78 x 10^6/year, Linsky, 1998) water shortages are now also common in many parts of the world. One way to maximize the use of existing water supplies is to employ multiple-use strategies involving water reuse. Clearly, the value of water must and will change in the future, and as it does, the role and importance of water reuse will continue to expand.

6.2 Technological issues

As discussed above and summarized in Table 2, a wide range of suitable technologies is now available that can be used to produce any required water quality. Also, as noted previously, the cost of these technologies is continuing to decrease. What is missing is: (1) a consistent set of criteria that can be used to assess performance and allow for valid comparisons between existing and developing technologies, (2) well developed reliability measures defined in terms of the proposed reuse application, and (3) well documented fail-safe measures. These issues must be resolved, if wide public acceptance of water reuse is to be achieved.

6.3 Regulatory requirements

Many of the existing standards are based on past experience and on limited and, in some cases, poor science. As a result, different standards are in use throughout the world. Further the relationship between many of the water quality indicators now used and public health is unclear. For example, the shellfish standard in the United States is based on coliform organism. But in fact, the biggest concern for shellfish may be *Cryposporidium* oocysts and *Giardia* cysts. Finally, many of the existing regulatory standards are inconsistent, including the use of MS2 coliphage as an indicator organism for the evaluation of process performance. Based on recent studies, it is now known that MS2 coliphage is a far more resistant organism than some of the organisms used in the past to develop water quality and treatment performance standards.

6.4 Social issues

The principal social issues related to reuse are: (1) public perception, (2) public trust, and (3) public acceptance. Although difficult to quantify, public perception is of key importance in the acceptance of reclamation projects. In many cases, the public does not trust the ability of the operating agency to produce consistently a treated water that meets all of the applicable requirements. Clearly, this mistrust must be overcome if wastewater reuse is to be accepted by the public.

7 Summary

The concept of decentralized wastewater management in the development of water resources has been introduced and discussed. Potential reuse applications have been reviewed as a basis for assessing the need for, and application of, alternative technologies. With the advances made in the technologies for both decentralized and centralized systems, it is now possible to produce an effluent water quality of any desired quality. Because water, historically, has been under valued, multiple-use strategies involving water reuse have not been developed fully. The challenge is to use treated effluent in a manner that will result in a sustainable environment, especially as the value of water increases in the future. Finally, to achieve the goal of greater wastewater reuse, it will be necessary to resolve health related issues and to focus future attention on social issues

Acknowledgments

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References

Craun, G. F., P. S. Berger, and R.L. Calderon (1997) Coliform Bacteria and Waterborne Disease Outbreaks, Journal AWWA, Vol. 89, Issue 3.

Crites, R. W., and G. Tchobanoglous (1998) *Small and Decentralized Wastewater Management Systems*, McGraw-Hill Book Company, New York, NY.

Frank, L. C. and C. P. Rhynus (1920) *The Treatment Of Sewage From Single Houses And Small Communities*, Public Health Bulletin No. 101, United States Public Health Service, Washington, DC.

Linsky, R. (1998) "What Is The Real Value Of Water," Briefings, Water Research Institute, Vol. 7, No. 2, Fountain Valley, CA.

Lumsden, L. L., C. W. Stiles, and A. W. Freeman (1915) *Safe Disposal Of Human Excreta At Unsewered Homes*, Public Health Bulletin No.68, United States Public Health Service, Government Printing Office, Washington, D.C.

Tchobanoglous, G. and F. L. Burton (Written and revised by) (1991) *Wastewater Engineering: Treatment, Disposal, Reuse*, 3rd ed., Metcalf & Eddy, Inc., McGraw-Hill Book Company, New York, NY.

Tchobanoglous, G. (1995) "Decentralized Systems for Wastewater Management," Paper presented at The 24th Annual WEAO Technical Symposium, Toronto, Canada

Tchobanoglous, G. (1998) "Appropriate Technologies For The Repurification Of Wastewater From Decentralized Systems For Reuse Applications, presented at the Southwest On-Site Wastewater Conference and Exhibit, Laughlin, NV.

WCPH (1996) Total Resource Recovery Project, Final Report, Prepared for City of San Diego, Water Utilities Department, Western Consortium for Public Health, Oakland CA.