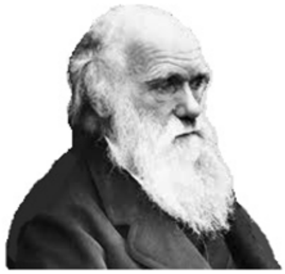
Available online at www.worldnewsnaturalsciences.com



World News of Natural Sciences

WNOFNS 5 (2016) 33-41 EISSN 2543-5426

Wastewater reuse

Janusz Wilas[1,*], Beata Draszawka-Bołzan[2], Emil Cyraniak[3]

[1]Department of Horticulture, Faculty of Environmental Management and Agriculture, West Pomeranian University of Technology, 17 Słowackiego Str., 71-434 Szczecin, Poland

[2]Faculty of Biology, University of Szczecin, 13 Waska Street, 71-415 Szczecin, Poland

[3]The Board of Marine Ports of Szczecin and Świnoujście S.A., Environment and Health Research Laboratory, 7 Bytomska Street, 70-603 Szczecin, Poland

*E-mail address: Janusz.Wilas@zut.edu.pl

ABSTRACT

Once freshwater has been used for an economic or beneficial purpose, it is generally discarded as waste. In many countries, these wastewaters are discharged, either as untreated waste or as treated effluent, into natural watercourses, from which they are abstracted for further use after undergoing "self-purification" within the stream. Through this system of indirect reuse, wastewater may be reused up to a dozen times or more before being discharged to the sea. Such indirect reuse is common in the larger river systems of Latin America. However, more direct reuse is also possible: the technology to reclaim wastewaters as potable or process waters is a technically feasible option for agricultural and some industrial purposes (such as for cooling water or sanitary flushing), and is a largely experimental option for the supply of domestic water. Wastewater reuse for drinking raises public health, and possibly religious, concerns among consumers. The adoption of wastewater treatment and subsequent reuse as a means of supplying freshwater is also determined by economic factors. Human excreta and wastewater contains useful materials. These are water, organic carbon and nutrients and should be regarded as a resource. In their natural cycles, they are broken down by micro-organisms and become accessible to plants and animals, thus sustaining natural ecosystems. When improperly disposed, these substances can cause pollution. This is because the organic materials exert oxygen demand, and the nutrients promote algal growth in lakes, rivers and near-shore marine environments. Human excreta and wastewater also contain pathogens. Reuse of the wastes must ensure that public health is maintained. Planned reuse is the key to wastewater reuse. Planning for reuse ensures that public health and protection of the environment are taken into account. Reuse of treated wastewater for irrigation of crops, for example, will need to meet (i) standards for indicator pathogens, and (ii) plant requirement for water, nitrogen and phosphorus. WHO and others have developed standards for reuse of wastewater for various purposes. Further details of these standards can be found in the Regional

Overviews in the Source Book, published by IWA and IETC. It must be pointed out, however, that requirements for water and nutrients are plant-specific and site-specific (dependent on soil type and climate), and information on these requirements need to be obtained from local information sources.

***Keywords*:** small wastewater treatment plants, technology selection, wastewater reuse

1. INTRODUCTION

Once freshwater has been used for an economic or beneficial purpose, it is generally discarded as waste. In many countries, these wastewaters are discharged, either as untreated waste or as treated effluent, into natural watercourses, from which they are abstracted for further use after undergoing "self-purification" within the stream. Through this system of indirect reuse, wastewater may be reused up to a dozen times or more before being discharged to the sea. Such indirect reuse is common in the larger river systems of Latin America. However, more direct reuse is also possible: the technology to reclaim wastewaters as potable or process waters is a technically feasible option for agricultural and some industrial purposes (such as for cooling water or sanitary flushing), and a largely experimental option for the supply of domestic water. Wastewater reuse for drinking raises public health, and possibly religious, concerns among consumers. The adoption of wastewater treatment and subsequent reuse as a means of supplying freshwater is also determined by economic factors.

In many countries, water quality standards have been developed governing the discharge of wastewater into the environment. Wastewater, in this context, includes sewage effluent, stormwater runoff, and industrial discharges. The necessity to protect the natural environment from wastewater-related pollution has led to much improved treatment techniques. Extending these technologies to the treatment of wastewaters to potable standards was a logical extension of this protection and augmentation process.

2. TECHNICAL DESCRIPTION

One of the most critical steps in any reuse program is to protect the public health, especially that of workers and consumers. To this end, it is most important to neutralize or eliminate any infectious agents or pathogenic organisms that may be present in the wastewater. For some reuse applications, such as irrigation of non-food crop plants, secondary treatment may be acceptable. For other applications, further disinfection, by such methods as chlorination or ozonation, may be necessary.

A typical example of wastewater reuse is the system at the Sam Lords Castle Hotel in Barbados. Effluent consisting of kitchen, laundry, and domestic sewage ("gray water") is collected in a sump, from which it is pumped, through a comminutor, to an aeration chamber. No primary sedimentation is provided in this system, although it is often desirable to do so. The aerated mixed liquor flows out of the aeration chamber to a clarifier for gravity separation. The effluent from the clarifier is then passed through a 16-foot-deep chlorine disinfection chamber before it is pumped to an automatic sprinkler irrigation system. The irrigated areas are divided into sixteen zones; each zone has twelve sprinklers. Some areas are also provided with a drip irrigation system. Sludge from the clarifier is pumped, without thickening, as a slurry to suckwells, where it is disposed of. Previously the sludge was pumped out and sent to the Bridgetown Sewage Treatment Plant for further treatment and additional desludging.

Table 1 presents a range of typical survival times for potential pathogens in water and other media.

Table 1. Typical Pathogen Survival Times at 20-30 °C (in days)

Pathogen	Freshwater and sewage	Crops	Soil
Viruses	< 120 but usually <50	<60 but usually < 15	<100 but usually <20
Bacteria	<60 but usually <30	<3 0 but usually < 15	<70 but usually <20
Protozoa	<30 but usually <15	<10 but usually <2	<70 but usually <20
Helminths	Many months	<60 but usually <30	Many months

Source: U.S. Environmental Protection Agency, *Process Design Manual: Guidelines/or Water Reuse.* Cincinnati, Ohio, 1992 (Report No. EPA-625/R-92-004).

3. EXTENT OF USE

Table 2. Guidelines for Water Reuse.

<table>
<tr><th>Type of Reuse</th><th>Treatment Required</th><th>Reclaimed Water Quality</th><th>Recommended Monitoring</th><th>Setback Distances</th></tr>
<tr><td>AGRICULTURAL</td><td rowspan="5">Secondary Disinfection</td><td>pH = 6-9</td><td>pH weekly</td><td rowspan="3">300 ft from potable water supply wells</td></tr>
<tr><td rowspan="2">Food crops commercially processed</td><td>BOD £ 30 mg/l</td><td>BOD weekly</td></tr>
<tr><td>SS = 30 mg/l</td><td>SS daily</td></tr>
<tr><td rowspan="2">Orchards and Vinerds</td><td>FC £ 200/100 ml</td><td>FC daily</td><td rowspan="2">100 ft from areas accessible to public</td></tr>
<tr><td>Cl_2 residual = 1 mg/l min.</td><td>Cl_2 residual continuous</td></tr>
<tr><td>PASTURAGE</td><td rowspan="4">Secondary Disinfection</td><td>pH = 6-9</td><td>pH weekly</td><td rowspan="3">300 ft from potable water supply wells</td></tr>
<tr><td rowspan="2">Pasture for milking animals</td><td>BOD £ 30 mg/l</td><td>BOD weekly</td></tr>
<tr><td>SS £ 30 mg/l</td><td>SS daily</td></tr>
<tr><td>Pasture for livestock</td><td>FC £ 200/100 ml</td><td>FC daily</td><td>100 ft from areas</td></tr>
</table>

		Cl_2 residual = 1 mg/l min.	Cl_2 residual continuous	accessible to public
FORESTATION	Secondary Disinfection	pH = 6-9	pH weekly	300 ft from potable water supply wells
		BOD £ 30 mg/l	BOD weekly	
		SS £ 30 mg/l	SS daily	
		FC £ 200/100 ml	FC daily	100 ft from areas accessible to the public
		Cl_2 residual = 1 mg/l min.	Cl_2 residual continuous	
AGRICULTURAL	Secondary Filtration Disinfection	pH = 6-9	pH weekly	50 ft from potable water supply wells
Food crops not commercially processed		BOD £ 30 mg/l	BOD weekly	
		Turbidity £ 1 NTU	Turbidity daily	
		FC = 0/100 ml	FC daily	
		Cl_2 residual = 1 mg/l min.	Cl_2 residual continuous	
GROUNDWATER RECHARGE	Site-specific and use-dependent	Site-specific and use-dependent	Depends on treatment and use	Site-specific

Source: USEPA, *Process Design Manual: Guidelines for Water Reuse*, Cincinnati, Ohio, 1992, (Report No. EPA-625/R-92-004).

For health and aesthetic reasons, reuse of treated sewage effluent is presently limited to non-potable applications such as irrigation of non-food crops and provision of industrial cooling water. There are no known direct reuse schemes using treated wastewater from sewerage systems for drinking. Indeed, the only known systems of this type are experimental in nature, although in some cases treated wastewater is reused indirectly, as a source of aquifer recharge. Table 2 presents some guidelines for the utilization of wastewater, indicating the type of treatment required, resultant water quality specifications, and appropriate setback distances. In general, wastewater reuse is a technology that has had limited use, primarily in small-scale projects in the region, owing to concerns about potential public health hazards. Wastewater reuse in the Caribbean is primarily in the form of irrigation water. In Jamaica, some hotels have used wastewater treatment effluent for golf course irrigation, while the major industrial water users, the bauxite/alumina companies, engage in extensive recycling of their process waters (see case study in Part C, Chapter 5). In Barbados, effluent from an extended aeration sewage treatment plant is used for lawn irrigation (see case study in Part C, Chapter 5). Similar use of wastewater occurs on Curaçao.

In Latin America, treated wastewater is used in small-scale agricultural projects and, particularly by hotels, for lawn irrigation. In Chile, up to 220 l/s of wastewater is used for irrigation purposes in the desert region of Antofagasta. In Brazil, wastewater has been extensively reused for agriculture. Treated wastewaters have also been used for human consumption after proper disinfection, for industrial processes as a source of cooling water, and for aquaculture. Wastewater reuse for aquacultural and agricultural irrigation purposes is also practiced in Lima, Peru. In Argentina, natural systems are used for wastewater treatment. In such cases, there is an economic incentive for reusing wastewater for reforestation, agricultural, pasturage, and water conservation purposes, where sufficient land is available to do so. Perhaps the most extensive reuse of wastewater occurs in Mexico, where there is large-scale use of raw sewage for the irrigation of parks and the creation of recreational lakes.

In the United States, the use of reclaimed water for irrigation of food crops is prohibited in some states, while others allow it only if the crop is to be processed and not eaten raw. Some states may hold, for example, that if a food crop is irrigated in such a way that there is no contact between the edible portion and the reclaimed water, a disinfected, secondary-treated effluent is acceptable. For crops that are eaten raw and not commercially processed, wastewater reuse is more restricted and less economically attractive. Less stringent requirements are set for irrigation of non-food crops.

International water quality guidelines for wastewater reuse have been issued by the World Health Organization (WHO). Guidelines should also be established at national level and at the local/project level, taking into account the international guidelines. Some national standards that have been developed are more stringent than the WHO guidelines. In general, however, wastewater reuse regulations should be strict enough to permit irrigation use without undue health risks, but not so strict as to prevent its use. When using treated wastewater for irrigation, for example, regulations should be written so that attention is paid to the interaction between the effluent, the soil, and the topography of the receiving area, particularly if there are aquifers nearby.

2. OPERATION AND MAINTENANCE

The operation and maintenance required in the implementation of this technology is related to the previously discussed operation and maintenance of the wastewater treatment processes, and to the chlorination and disinfection technologies used to ensure that pathogenic organisms will not present a health hazard to humans. Additional maintenance includes the periodic cleaning of the water distribution system conveying the effluent from the treatment plant to the area of reuse; periodic cleaning of pipes, pumps, and filters to avoid the deposition of solids that can reduce the distribution efficiency; and inspection of pipes to avoid clogging throughout the collection, treatment, and distribution system, which can be a potential problem. Further, it must be emphasized that, in order for a water reuse program to be successful, stringent regulations, monitoring, and control of water quality must be exercised in order to protect both workers and the consumers.

3. LEVEL OF INVOLVEMENT

The private sector, particularly the hotel industry and the agricultural sector, are becoming involved in wastewater treatment and reuse. However, to ensure the public health and protect the environment, governments need to exercise oversight of projects in order to minimize the deleterious impacts of wastewater discharges. One element of this oversight should include the sharing of information on the effectiveness of wastewater reuse. Government oversight also includes licensing and monitoring the performance of the wastewater treatment plants to ensure that the effluent does not create environmental or health problems.

4. COSTS

Cost data for this technology are very limited. Most of the data relate to the cost of treating the wastewater prior to reuse. Additional costs are associated with the construction of a dual or parallel distribution system. In many cases, these costs can be recovered out of the savings derived from the reduced use of potable freshwater (i.e., from not having to treat raw water to potable standards when the intended use does not require such extensive treatment). The feasibility of wastewater reuse ultimately depends on the cost of recycled or reclaimed water relative to alternative supplies of potable water, and on public acceptance of the reclaimed water. Costs of effluent treatment vary widely according to location and level of treatment (see the previous section on wastewater treatment technologies). The degree of public acceptance also varies widely depending on water availability, religious and cultural beliefs, and previous experience with the reuse of wastewaters.

5. CONCLUSIONS

Treated wastewater from off-site treatment plants can be reused for irrigation of parks and gardens, agriculture and horticulture, tree plantation and aquaculture, if these exist or can be established not far from the wastewater treatment plants. For these purposes the wastewater should generally be treated to secondary wastewater standard (< 20 mg/L BOD and < 30 mg/L SS). Total coliforms should be < 1000 organisms per 100 mL for irrigation by spraying. When sub-surface irrigation is used this requirement may not be necessary. A period of non-entry to irrigated sites may need to be observed, particularly for wastewater-irrigated parks and gardens. Irrigation of vegetables for direct human consumption requires a much stricter guideline.

Because requirement of wastewater for plant growth is governed by climatic conditions, soil and plant type, there may be a need for storage of the wastewater. An alternative to storage, if land area is not available for this purpose, is to dispose of wastewater that is excess to requirement. A combination of wastewater for irrigation and aquaculture (see below) is also an option that can be considered.

Wastewater reuse for aquaculture has been practised in many countries for a considerable period of time. It has the potential of wider application in the tropics. There is great diversity of systems involving cultivation of aquatic species, (mainly fish) and plants (mainly aquatic vegetables such as water spinach). The Source Book, published by IWA and IETC, contains a detailed section on aquaculture and a case study is presented in the Regional Overview for Central & South America.

Farmers and local communities have developed most reuse systems; the primary motivating factor has been reuse of nutrients for food production rather than wastewater treatment, and with scant attention to either waste treatment or to public health. In most aquaculture systems, wastewater is not reused directly in aquaculture and the nutrients contained in the wastewater are used as fertiliser to produce natural food such as plankton for fish. These nutrients, mainly nitrogen and phosphorus, are also taken up directly by large aquatic plants such as duckweed which is cultivated for animal feed, and aquatic vegetables such as water spinach and water mimosa cultivated for human food.

References

[1] Ackermann GE, Schwaiger J, Negele RD, Fent K (2002). Effects of long-term nonylphenol exposure on gonadal development and biomarkers of estrogenicity in juvenile rainbow trout (Oncorhynchus mykiss). Aquat Toxicol 60(3-4): 203-221

[2] An L, Hu J, Yang M (2008). Evaluation of estrogenicity of sewage effluent and reclaimed water using vitellogenin as a biomarker. Environ Toxicol Chem 27(1): 154-158

[3] Aragonés-Beltrána P, Mendoza-Rocab J A , Bes-Piáa A et al. (2009). Application of multi-criteria decision analysis to jar-test results for chemicals selection in the physical–chemical treatment of textile wastewater. Journal of Hazardous Materials 164 (2009), pp. 288-295.

[4] Balkema, A., Weijers S., and Lambert F. (1998). On Methodologies for Comparison of Wastewater Treatment Systems with Respect to Sustainability. Conference "Options for Closed Water Systems", 11-13 March, 1998, Wageningen, Netherlands

[5] Belton, V., Stewart, T., (2002). Multiple Criteria Decision Analysis. An Integrated Approach. Kluwer Academic Publishers.

[6] Bila D, Montalvao AF, Azevedo DdA, Dezotti M (2007). Estrogenic activity removal of 17β-estradiol by ozonation and identification of by-products. Chemosphere 69(5):736-746

[7] Bjerregaard LB, Madsen AH, Korsgaard B, Bjerregaard P (2006). Gonad histology and vitellogenin concentrations in brown trout (Salmo trutta) from Danish streams impacted by sewage effluent. Ecotoxicology 15(3):315-327

[8] Bjerregaard P, Hansen PR, Larsen KJ, Erratico C, Korsgaard B, Holbech H (2008). Vitellogenin as a biomarker for estrogenic effects in brown trout, Salmo trutta: laboratory and field investigations. Environ Toxicol Chem 27(11):2387-2396

[9] Bolong N, Ismail A, Salim MR, Matsuura T (2009). A review of the effects of emerging contaminants in wastewater and options for their removal. Desalination 239(1):229-246

[10] Bradford, A.; Brook, R.; Hunshal, C. S. 2003. Wastewater irrigation in Hubli–Dharwad, India: Implications for health and livelihoods. Environment and Urbanization 15(2): 157-170.

[11] Brechet T., Tulkens H. (2009). Beyond BAT: Selecting optimal combinations of available techniques, with an example from the limestone industry. Journal of Environmental Management 90 (2009), pp. 1790-1801.

[12] Bruvold, W. 1988. Public opinion on water reuse options. Journal WPCF 60(1): 45-49.

[13] Buechler, S.; Mekala, G. D.; Raschid-Sally, L. 2002. Livelihoods and Wastewater Irrigated Agriculture along the Musi River in Hyderabad City, Andhra Pradesh, India. Urban Agriculture Magazine 8: 14-17.

[14] Chattopadhyay, K. 2004. Jalabhumir Kolkata – a fact-finding observation of East Calcutta Wetlands. Kolkata (publisher unknown).

[15] Copeland PA, Sumpter JP, Walker TK, Croft M (1986). Vitellogenin levels in male and female rainbow trout (Salmo gairdneri richardson) at various stages of the reproductive cycle. Comp Biochem Physiol Part B Comp Biochem 83(2): 487-493

[16] Davey, A.; Miller, P.; Knops, F. 2005. Australia's Largest Ultra-Filtration Reclaimed Water Plant, Water 32(2), March 2005.

[17] Georgopoulou, E., Hontou, V., Gakis et al. (2008), BEAsT: a decision-support tool for assessing the environmental benefits and the economic attractiveness of best available techniques in industry. Journal of Cleaner Production Vol. 16, No 3.

[18] Jobling S (1998) Natural and anthropogenic environmental oestrogens: the scientific basis for risk assessment. Pure Appl Chem 70(9): 1805-1827

[19] Kime DE, Nash JP, Scott AP (1999) Vitellogenesis as a biomarker of reproductive disruption by xenobiotics. Aquaculture 177(1-4): 345-352

[20] Lange R, Hutchinson TH, Croudace CP, Siegmund F, Schweinfurth H, Hampe P, et al. (2001) Effects of the synthetic estrogen 17 alpha-ethinylestradiol on the life-cycle of the fathead minnow (Pimephales promelas). Environ Toxicol Chem 20(6):1216-1227.

[21] Pickering A, Pottinger T, Carragher J (1989) Differences in the sensitivity of brown trout, Salmo trutta L., and rainbow trout, Salmo gairdneri Richardson, to physiological doses of cortisol. J Fish Biol 34(5): 757-768

[22] Purdom CE, Hardiman PA, Bye VVJ, Eno NC, Tyler CR, Sumpter JP (1994). Estrogenic Effects of Effluents from Sewage Treatment Works. Chem Ecol 8(4): 275-285.

[23] Routledge EJ, Sheahan D, Desbrow C, Brighty GC, Waldock M, Sumpter JP (1998). Identification of estrogenic chemicals in STW effluent. 2. In vivo responses in trout and roach. Environ Sci Technol 32(11): 1559-1565

[24] Schmidt H, Bernet D, Wahli T, Meier W, Burkhardt-Holm P (1999). Active biomonitoring with brown trout and rainbow trout in diluted sewage plant effluents. J Fish Biol 54(3): 585-596

[25] Schneeberger HU (1995). Abklärungen zum Gesundheitszustand von Regenbogenforelle (Oncorhynchus mykiss), Bachforelle (Salmo trutta fario) und Groppe (Cottus gobio) im Liechtensteiner, Werdenberger- und Rheintaler-Binnenkanal [Inaugural Dissertation]: University of Bern, Bern

[26] Stalter D, Magdeburg A, Wagner M, Oehlmann J (2011). Ozonation and activated carbon treatment of sewage effluents: removal of endocrine activity and cytotoxicity. Water Res 45(3): 1015-1024

[27] Stalter D, Magdeburg A, Weil M, Knacker T, Oehlmann J (2010). Toxication or detoxication? In vivo toxicity assessment of ozonation as advanced wastewater treatment with the rainbow trout. Water Res 44(2): 439-448

[28] Sumpter JP (1998). Xenoendocrine disrupters—environmental impacts. Toxicol Lett 102: 337-342

[29] Sumpter JP, Jobling S (1995). Vitellogenesis as a biomarker for estrogenic contamination of the aquatic environment. Environ Health Perspect 103 (Suppl 7): 173

[30] Triebskorn R, Amler K, Blaha L, Gallert C, Giebner S, Güde H, et al. (2013). SchussenAktivplus: reduction of micropollutants and of potentially pathogenic bacteria for further water quality improvement of the river Schussen, a tributary of Lake Constance, Germany. Environ Sci Eur 25(1): 1-9

[31] Triebskorn R, Hetzenauer H (2012). Micropollutants in three tributaries of Lake Constance, Argen, Schussen and Seefelder Aach: a literature review. Environ Sci Eur 24(1): 1-24

[32] Tyler CR, van Aerle R, Hutchinson TH, Maddix S, Trip H (1999). An in vivo testing system for endocrine disruptors in fish early life stages using induction of vitellogenin. Environ Toxicol Chem 18(2): 337-347

[33] Spijkerman E, Coesel PFM, 1998. Alkaline phosphatase activity in two planktonic desmid species and the possible role of an extracellular envelope. Freshw Biol 39: 503-513. doi:10.1046/j.1365-2427.1998.00299.x

[34] Štrojsová A, Vrba J, Nedoma J, Komárková J, Znachor P, 2003. Seasonal study on expression of extracellular phosphatases in the phytoplankton of an eutrophic reservoir. Eur J Phycol 38: 295-306 doi:10.1080/09670260310001612628

[35] Štrojsová A, Vrba J, Nedoma J, Šimek K, 2005. Extracellular phosphatase activity of freshwater phytoplankton exposed to different in situ phosphorus concentrations. Mar Freshw Res 56: 417-424 doi:10.1071/MF04283

[36] Taga N, Kobori H, 1978. Phosphatase activity in eutrophic Tokyo Bay. J. Mar Biol (Berl) 49: 223-229. doi:10.1007/BF00391134

[37] Vrba J, Komárková J, Vyhnálek V, 1993. Enhanced activity of alkaline phosphatases-phytoplankton response to epilimnetic phosphorus depletion. Water Sci Technol 28: 15-24

[38] Yu S., Hea Z.L., Stoffellaa P.J., Calverta D.V., Yanga X.E., Banksa D.J., Baligar V.C., 2006. Surface runoff phosphorus (P) loss in relation to phosphatase activity and soil P fractions in Florida sandy soils under citrus production. Soil Biology & Biochemistry 38, 619-628.

(Received 14 September 2016; accepted 25 October 2016)