Reuse of Treated Sewage

Easy reference to US EPA and WHO Guidelines and Regulations

Series Editor: M.Sohail

Compiled by John McArdle

WEDC

Loughborough University

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BILL & MELINDA GATES foundation

In 2011, the Water, Sanitation & Hygiene program at the Bill & Melinda Gates Foundation initiated the Reinvent the Toilet Challenge to bring sustainable sanitation solutions to the 2.5 billion people worldwide who don't have access to safe, affordable sanitation.

Grants have since been awarded to researchers and industries around the world who are using innovative approaches – based on fundamental engineering processes – for the safe and sustainable management of human waste. The Reinvent the Toilet Challenge aims to create a toilet that:

- Removes germs from human waste and recovers valuable resources such as energy, clean water, and nutrients.
- Operates 'off the grid' without connections to water, sewer, or electrical lines.
- Costs less than US$.05 cents per user per day.
- Promotes sustainable and financially profitable sanitation services and businesses that operate in poor, urban settings.
- Is a truly aspirational next-generation product that everyone will want to use – in developed as well as developing nations.

Innovative solutions change people's lives for the better. By applying creative thinking to everyday challenges, such as dealing with human waste, we can fix some of the world's toughest problems.

Doulaye Kone, PhD
Senior Program Officer, WSH, Toilet Team
Transformatives Technologies
Global Development

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Preface

Based at Loughborough University, I have been leading research and development of reinvented toilet activities funded by the Bill & Melinda Gates foundation since 2011.

The guiding objective of the our toilet is to safely eliminate known pathogens while recovering scarce resources from waste; the recovered resources can then be used to finance safer disposal in a user-friendly and socially acceptable manner at household levels. The toilet's configuration eliminates the difficulty of separating urine and excreta, and may also take in other organic waste, such as sanitary napkins and food products.

We have contributed in the body of knowledge though journal articles, conference papers, books and reports. This compilation is one of the project outputs. Besides direct relevance to the project in exploring options for reuses of treated sewage, this will interest other research colleagues, practitioners and students working on similar issues.

The report is a quick guide to relevant environmental standards and guides.

Professor M.Sohail Khan
BEng, MSc, PhD Loughborough, Fellow ASCE (USA)
Professor of Sustainable Infrastructure
Water, Engineering and Development Centre (WEDC)
School of Civil and Building Engineering
Loughborough University

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Acronyms

AAR	=	annual application rate (gals/acre/year)
CFR	=	Code of Federal Regulations (United States)
CCWA	=	Clean Water Act (United States)
DALY	=	Disability Adjusted Life Year
FAO	=	Food and Agriculture Organization (United Nations)
HTC	=	hydrothermal carbonization
MPN	=	most probable number
PFC	=	plaque forming colonies
PFU	=	plaque forming units
PFRP	=	processes that further reduce pathogens
SPS Agreement	=	Sanitary and Phytosanitary Measures Agreement
TDS	=	total dissolved solids
USEPA	=	United States Environmental Protection Agency
WTO	=	World Trade Organization

Terms

Aerobic digestion = Biological sewage treatment with oxygen available
Anaerobic digestion = Biological sewage treatment with reduced oxygen available
Biochar = Organic solid product of pyrolysis, including hydrothermal carbonization (HTC)
Biomass = Organic material produced by biological processes; i.e., plant-based materials
Biosolid = Organic solid material produced in sewage treatment plant
Class A Biosolid = Treated biosolid with reduced pathogens for unrestricted irrigation
Class B Biosolid = Treated biosolid with reduced pathogens for restricted irrigation
Conductivity (TDS) = Indicator of salt concentration in water
Direct reuse = Discharge recovered water from sewage to drinking water reservoir
E. coli = Bacteria from intestinal track of mammals, used as indicator of faecal contamination
Enteric viruses = Viral entities contained in faecal material
Helminth ova = Eggs of parasitic worms
Indirect reuse = Discharge recovered water from sewage to groundwater percolation field
Industrial wastewater = Wastewater from manufacturing operations
Log reduction = Mathematic term for reduction of microbes; i.e., 1 log = 90% removal
Nutrients = Elements needed for biological growth; i.e., nitrogen and phosphorus
Pathogen = Infectious agent including virus, bacteria or parasite that causes disease in host
Primary wastewater treatment = Physical treatment; i.e., gravity settling and floatation
Pyrolysis = Decomposition of organics at elevated temperature in the absence of oxygen
Secondary wastewater treatment = Biological treatment; i.e., activated sludge process
Sewage (domestic sewage) = Wastewater from house toilets, showers, washing etc.
Sewage sludge = Solid or semi-solid residual material from sewage treatment
Septage = Sewage from a septic system
Vectors = Rodents and insects that can spread disease by transferring pathogens
Wastewater = Contaminated water discharged from municipal or industrial operations

Summary

Loughborough University, under a grant from the Bill & Melinda Gates Foundation – Reinvent the Toilet Challenge (RTTC), has demonstrated a hydrothermal carbonization (HTC) pyrolysis-type process that converts mixed, domestic sewage into biological charcoal (biochar) under high-temperature, low-oxygen conditions. This process generates biochar, nutrients and water for potential beneficial reuse.

In this report, guidelines and regulations from the United States Environmental Protection Agency (USEPA) and the World Health Organization (WHO) are described that cover treatment, handling and beneficial reuse of domestic sewage. A review of this information has identified potentially relevant guidelines and regulations to allow for the beneficial reuse of nutrients and water from the HTC process, including what might be required to obtain the necessary regulatory approval for specific sewage reuse options and practices.

Findings and conclusions

Based on the following review of USEPA and WHO guidelines and regulations for sewage reuse, and contingent on completing performance validation and conforming to the required monitoring practices, it is believed that with the temperature and residence time conditions of the HTC process, reduced pathogen loading of recovered solids and water from sewage will be adequate to allow unrestricted use in irrigation.

Specifically, under WHO guidelines, confirmation that sewage treatment reduces indicator pathogen bacteria to $\leq 10^3$ *E. coli*/100ml allows for unrestricted irrigation[1]. Under USEPA regulations, treatment of sewage sludge at temperatures of $\geq 50^{o}$C for ≥ 30 minutes with confirmation that the density of faecal coliform is <1,000 MPN (most probable number) per gram total solids or the density of *Salmonella* bacteria is <3 MPN per 4 grams total solids or, alternatively, confirming that a known treatment process also reduces the density of enteric viruses in sewage sludge to <1 PFU (plaque-forming unit) per 4 grams total solids and viable helminth ova to <1 per 4 grams total solids allows for unrestricted irrigation[2]. Certain specified vector reduction practices are also required under USEPA regulations.

In addition to the above pathogen considerations, WHO and USEPA provide guidelines and regulations that limit certain metal contaminants in treated sewage, irrigated soil or both. Finally, nutrient and salt (conductivity) agronomical loading limits must be addressed on a case-by-case basis to ensure effective reuse of sewage for irrigation that avoids negative environmental impacts.

Regarding the beneficial reuse of biochar, a limited review of various online publications [3,4] indicates a critical lack of data to draw conclusions about how biochar impacts crop yield, soil fertility and water retention, or build-up of greenhouse gas in the atmosphere. However, it appears likely that waste biomass, including organic sewage solids, is

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[1] WHO *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 2: Wastewater Use in*
[2] 40 CFR 503, Subpart D, Section §503.32, Pathogens.
[3] Brick Madison, Stephen, November 2010. 'Biochar: Assessing the Promise and Risks To Guide U.S. Policy'. Issue Paper, National Resources Defense Council, Wisconsin.
[4] Gurwick, N.P., Moore L.A., Kelly C. and Elias P., 2013. A Systematic Review of Biochar Research, with a Focus on Its Stability in situ and Its Promise as a Climate Mitigation Strategy.

preferable to primary biomass as a biochar feedstock[5]. Nevertheless, significant additional field work and research studies are required to determine biochar stability, soil interactions under different environmental conditions, alternative uses of biomass, and greenhouse gas budgets over long and short timescales.

Nutrients and water produced from sewage with the HTC process are potentially available for beneficial reuse and biochar, which is generated at the same time, must be managed. Practical handling, storage and distribution of these materials must be addressed, taking into consideration existing family unit, local community and regional infrastructure.

Table 1 shows several methods that have been identified for the handling, storage and distribution of biochar, nutrients and water generated by the HTC process – including benefits and considerations for each of these methods.

Table 1
Handling, storage and distribution options for HTC recovered values

Method	**Benefit**	**Considerations**
Dedicated Collection Tank	Direct water reuse	Cost to install and maintain collection tank
(HTC system treats sewage only)	Recovery of high quality water	Potential biological contamination of collection tank
	High level of wastewater treatment	Potential for buildup of salts in groundwater
		Solids settled in collection tank require periodic removal
		Other household wastewater treated before discharge
Dedicated Percolation Field	Maintain groundwater table	No direct water reuse
(HTC system treats sewage only)	High level of wastewater treatment	Dedicated plot of land required for percolation field
		Proper soil condition required for adequate percolation
		Periodic removal of solids from surface of percolation field
		Potential vector (rodent/insect) attraction
		Potential for buildup of salts in groundwater
		Other household wastewater treated before discharge
Discharge to Surface Water	Maintain surface water quality	No direct water reuse
(HTC system treats sewage only)	High level of wastewater treatment	Removal of solids required before discharge
		Other household wastewater treated before discharge
Septic Tank/Leach Field	Single on-site treatment system	No direct water reuse
(No in-site HTC system installed)	Low level of wastewater treatment	Cost to install and maintain septic tank/leach field
		Periodic removal of solids from septic tank
Discharge to Community Sewer	No on-site treatment system	No direct water reuse
(No on-site HTC system installed)	Varying level of wastewater treatment	Requires investment in expensive sewer system

Direct reuse of treated sewage can be achieved in an efficient manner using a dedicated collection tank to store the recovered water until needed for irrigation. Biochar solids can be separated from the recovered water before the collection tank, or settled and periodically removed from the collection tank. Indirect reuse of treated sewage can be achieved using a percolation field that returns the recovered water to the aquifer, where it can be pumped to the surface as needed for irrigation. Biochar solids can be separated from the recovered water before the percolation field or periodically removed from the

[5] Brick Madison, Stephen, November 2010. 'Biochar: Assessing the Promise and Risks To Guide U.S. Policy'. Issue Paper, National Resources Defense Council, Wisconsin, p.iv.

surface layer of the percolation field. If these options are to achieve and maintain successful reuse of recovered water, nutrient and salt (conductivity) levels must be controlled in irrigated soil.

Recovered water from the HTC process can be discharged to local surface water. Treatment of sewage with the HTC process before discharge into surface water can reduce the environmental damage and negative human health issues that result from the discharge of untreated or partially treated sewage. However, with this method, the benefit of gaining a secure source of safe irrigation water is not realized. Accordingly, it is believed that in the majority of circumstances the direct or indirect reuse of recovered water for irrigation is preferable to its discharge into surface water.

Finally, recovered water from the HTC process can be discharged to a septic tank/leach field or to a sewer connected to a central sewage treatment plant. However, with this method there is no apparent justification for investment in the HTC process. In many cases it is expected that local treatment of sewage using the HTC process will have an advantage – for example, for urban or peri-urban sites in developing countries where there is inadequate land for installation of septic tanks and leach fields or a lack of investment capital and expertise to install, maintain and operate a very expensive sewer system and centralized sewage treatment plant.

Background

For decades, communities in more developed countries have reused highly-treated domestic sewage to recharge groundwater aquifers, irrigate landscapes and agricultural fields, and provide industries with an alternative to potable water for a range of different uses[6]. Domestic sewage, with varying degrees of treatment, is widely used in less developed countries for agriculture irrigation. This practice is increasingly considered a critical method to recycle water and nutrients that increases food security and improves human nutrition[7]. Policies that promote beneficial use of sewage should link environmental and health protection policies with food security to attain maximum health benefits through improved nutrition, while reducing health risks related to infectious diseases[8].

The principal forces that are driving increased sewage reuse, in both less developed and more developed countries, include: (1) increasing water scarcity and stress; (2) expanding populations; (3) lack of food security; (4) increasing environmental pollution from improper wastewater disposal; and (5) recognition of the resource value of sewage[9]. However, it is recognized that reuse of sewage presents potential risks to human health from a range of pathogens. In addition, where industrial wastes impact sewage, chemical pollutants may be present that can have negative impacts on human health and the environment. There is also concern about the potential damage to drinking water aquifers caused by the build-up of salts and other chemicals, including pharmaceuticals and personal care products. Finally, run-off from agricultural fields irrigated with sewage can overload receiving bodies of water with nutrients, including

[6] US Environmental Protection Agency, 2012. *Guidelines for Water Reuse*, EPA/600/R-12/618, p.iii.
[7] WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 1: Policy and Regulatory Aspects*, p.vii.
[8] Ibid., p.8.
[9] Ibid., p.8.

phosphorus and nitrogen, which can cause extensive environmental damage by harmful algal blooms and eutrophication.

Sewage reuse for irrigation is often officially prohibited, yet unofficially tolerated, because much of the local population derive their livelihoods from access to untreated or partially treated sewage. Sewage reuse occurs, for example, when sewage is knowingly taken from outfall pipes or drainage canals, because it is easily accessible at no cost or can confer benefit over other water sources because of high nutrient content.

Aquaculture using sewage has been practised for thousands of years, almost exclusively in Asia, as a method to manage human waste and produce fish protein[10]. Intentional use of domestic sewage in aquaculture is declining, in part because increased urbanization is reducing the available land for fishponds. However, unintentional use of sewage is likely increasing because surface waters used for aquaculture are increasingly being polluted with human waste[11].

In recognition of the above practices, the World Health Organization (WHO) and United States Environmental Protection Agency (USEPA) have published a series of documents that provide guidelines for the safe use of domestic sewage (Appendix 1). USEPA's *Guidelines for Water Reuse* and WHO's *Guidelines for the Safe Use of Wastewater, Excreta and Greywater* have had significant global influence with public health scientists, researchers, engineers and policy-makers, who use the information in these documents as a framework to develop their own locally appropriate standards and regulations.

In the United States, sewage reuse regulations are under the jurisdiction of state, tribal nation and territory authorities – there are no federal regulations. The most recent USEPA publication, released in 2012, includes a summary of the sewage reuse regulations and guidelines that have been adopted by these authorities. At the time of writing, 30 states had adopted regulations and 15 states had guidelines or design standards to govern sewage reuse. In states and countries where standards do not exist or are being revised, USEPA and WHO guidelines have been used to inform the development of regulations for sewage reuse practices that protect human health and the environment[12].

Previous WHO guidelines for sewage reuse were mainly based on conformance to specific water-quality thresholds. Unlike these earlier guidelines, current WHO guidelines, released in 2006, applied a comprehensive risk assessment and management framework that considers trade-offs between potential risks and benefits within a wider developmental context. This approach recognizes that conventional wastewater treatment may not always be feasible, particularly in resource-constrained settings, and offers alternative measures that can reduce the disease burden of sewage reuse[13].

[10] WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 3: Wastewater Use in Aquaculture*, p.7.
[11] WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 1: Policy and Regulatory Aspects*, p.7.
[12] US Environmental Protection Agency, 2012. *Guidelines for Water Reuse*, EPA/600/R-12/618, pp.1-2.
[13] Ibid., pp.9-14.

Sewage reuse in agriculture

More than 10 per cent of the world's population consumes foods produced by irrigation with domestic sewage[14]. This percentage is considerably higher in low-income countries with arid and semi-arid climates. Treated and untreated sewage are used directly and indirectly (i.e. as sewage-contaminated surface water) for irrigation in both developed and less developed countries. In places where highly contaminated surface water is used for irrigation, health and environmental problems of the same nature and magnitude can arise as with the use of treated and untreated sewage[15].

Today, the use of sewage from on-site sanitation systems – including unsewered household and public toilets – for irrigation in urban and peri-urban locations is widespread in developing countries. The majority of urban dwellers in these countries are served today, and will increasingly be served in the future, by such sanitation systems. Accordingly, adequate treatment of resulting sewage to attain safe biosolids and other reusable resources is a crucial goal to improve public health[16].

Rules that govern international trade in food were agreed to during the Uruguay Round of Multilateral Trade Negotiations. These rules apply to all of the members of the World Trade Organization (WTO). With regard to food safety, rules are set out in the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement), adopted in 1999. The SPS Agreement sets policies related to food safety – for example, bacterial contaminants, as well as animal and plant health (phytosanitation). Under this agreement, WTO members have the right to take legitimate measures to protect the life and health of their populations from hazards in food, provided that the measures are not unjustifiably restrictive of trade[17].

Guidelines for the international trade of sewage-irrigated food products should be based on scientifically sound risk assessment and management principles. The WHO *Guidelines for the Safe Use of Wastewater, Excreta and Greywater* in agriculture and aquaculture are based on a risk-analysis approach that is recognized internationally as the fundamental methodology underlying the development of food safety standards, which both provide adequate health protection and facilitate trade in food. Adherence to the WHO guidelines in the application of wastewater, excreta and greywater for the production of food products destined for export will help to ensure an unencumbered international trade in safe food products[18].

Hazards associated with sewage reuse for agriculture irrigation are shown in Table 2[19].

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[14] WHO, July 2014. Sanitation Fact Sheet No. 392. Available at: http://www.who.int/mediacentre/factsheets/fs392/en/

[15] WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 1: Policy and Regulatory Aspects*, p.6.

[16] Ibid., p.7.

[17] Ibid., p.9.

[18] Ibid., p.9.

[19] Adapted from WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 1: Policy and Regulatory Aspects*, Table 2.1, p.20.

Table 2
WHO guidelines – pathogen hazards with sewage reuse in agriculture

Hazard	Examples	Health Risk
Bacteria	*Escherichia coli*	Bacteria die off more rapidly on crops than
	Vibrio cholerae	some other pathogens but still present a health risk
	Salmonella	
	Shigella	
Helminths	*Ascaris*	Major health risk because eggs can survive
Soil-transmitted	*Ancylostoma*	in the environment for extended periods of time
	Strongyloides	
	Taenia	
	Necator	
	Hymenolepis	
	Toxocara	
	Trichuris	
Helminths	*Clonorchis*	Major health risk in aquaculture
Trematodes	*Fasciola*	in certain limited geographic areas
	Opisthorchis	
	Schistosoma	
Protozoa	*Giardia*	Protozoa can survive in the
	Cryptosporidium	environment long enough to pose health risk
	Cyclospora	
	Entamoeba	
Viruses	*Hepatitis*	Viruses can survive in the
	Adenovirus,	environment for long enough to pose health risks
	Rotavirus	
	Norovirus	

WHO guidelines recognize different health risks for different groups exposed to sewage reuse practices and establish specific health-based targets and measures to protect each group.

Epidemiological studies suggest that the following groups have significant risk of infection from pathogen exposure associated with sewage irrigation practices[20]:

- Product consumers

  Excess diarrheal diseases and cholera, typhoid and shigellosis risks; trematode (including schistosome) parasites by consuming raw or inadequately cooked fish[21].

[20] US Environmental Protection Agency, 2012. *Guidelines for Water Reuse*, EPA/600/R-12/618, pp.9-2.

- Farmers/families of farmers

  Excess parasitic, diarrheal and skin infection risks; high prevalence of hookworm disease and ascariasis infections among those who do not use protective gear.

- Local communities

  Risk of bacterial and viral infections through exposure to aerosols.

WHO has developed health-based targets that establish a defined level of health protection for a given exposure to these hazards. Targets based on a measure of the disease include disability adjusted life year (DALY) and absence of a specific disease related to exposure.

After health targets have been defined, a combination of health protection standards are specified by the regulators to achieve these health-based targets – for example, crop restriction; sewage application techniques; measures to control exposure; treatment processes; and handling practices to reduce risk.[22] This approach specifically considers risks to the health to consumers of food crops with unrestricted irrigation and health risks to field workers with restricted and localized irrigation.

Unrestricted irrigation includes irrigation of vegetable and salad crops that might be eaten uncooked. Restricted irrigation is limited to non-food crops (cotton), food crops that are processed before eating (wheat) or that need cooking (rice, potato), fodder, pasture and trees. Localized irrigation includes drip, bubbler and trickle irrigation that has a lower risk of farmworker exposure than spray irrigation.

WHO health-based targets for sewage reuse in agriculture are summarized in Table 3.[23]

Table 3
WHO health-based targets for wastewater use in agriculture

Type of Irrigation	**Health Based Target (viral, bacterial, protozoan pathogens)**	**Microbial Reduction Target (helminth eggs)**
Unrestricted	≤ 10^{-6} DALY per person per year	≤ 1 per litre (arithmetic mean*)
Restricted	≤ 10^{-6} DALY per person per year	≤ 1 per litre (arithmetic mean*)
Localized	≤ 10^{-6} DALY per person per year	Low growing crops **
		≤ 1 per litre (arithmetic mean*)
		High growing crops ***
		No recommendation

* Arithmetic mean calculated over the irrigation season with > 90% of the samples at ≤1 eggs per liter
** Low growing crops include leaf crops (lettuce) and root crops (onions)
*** High growing crops include fruit trees, olives, etc.

[21] WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 3: Wastewater Use in Aquaculture*, p.16.
[22] WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 1: Policy and Regulatory Aspects,* p.25.
[23] Adapted from WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 1: Policy and Regulatory Aspects*, Table 2.4, p.26.

It is necessary to determine required log removal of pathogens to achieve the above health-based targets. For unrestricted and localized irrigation, a total pathogen reduction of 6 log units for leaf crops (lettuce) and 7 log reduction for root crops (onions) is required to achieve the health-based target of $\leq 10^{-6}$ DALY per person per year[24]. For restricted irrigation, a total pathogen reduction is 4 log units for labour-intensive irrigation and 3 log units for highly mechanical irrigation practices to achieve the health-based target of $\leq 10^{-6}$ DALY per person per year[25].

The microbial reduction target of ≤1 helminth eggs per litre in the irrigation water is based on epidemiological and microbiological studies. However, this concentration of ≤1 helminth eggs per litre may not be sufficient in warm, moist soil conditions that favour egg survival, especially where children under the age of 15 are exposed by eating uncooked field vegetables. In these situations, additional protective measures are required to safeguard children, including treatment with antihelminthic drugs or washing vegetables in a weak detergent solution[26]. When localized irrigation is used with high-growing crops, specific limitations to helminth egg concentrations are not necessary[27].

Health-based targets can be achieved by applying health-protection measures to meet the required pathogen reduction.

WHO health-protection measures for sewage treatment, produce handling practices and irrigation methods, along with the corresponding pathogen log unit reductions, are shown in Table 4.[28]

Table 4
WHO health-protection measures and pathogen reduction

Protection Measures	Pathogen Reduction Log Unit
Treatment	1 to 6
Localized Drip Irrigation (Low Growing Crops)	2
Localized Drip Irrigation (High Growing Crops)	4
Spray Irrigation	1
Pathogen Die Off	0.5 to 2 (per day)
Produce Washing	1
Produce Peeling	2
Produce Cooking	6 to 7
Produce Disinfecting	2

The sum of the individual log unit reductions for each health-protection measure is equal to the pathogen log reduction. For example, combining a treatment process with 3 log

[24] WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 2: Wastewater Use in Agriculture*, p.63.
[25] Ibid., p.67.
[26] Ibid., p.67.
[27] Ibid., p.69.
[28] Adapted from WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 2: Wastewater Use in Agriculture*, Table 4.3, p.64.

unit removal with pathogen die off (2 log) and produce washing (1 log) provides total pathogen reduction of 7 log units.

For households and institutions, minimum treatment in a septic tank (0.5 log unit pathogen reduction) followed by subsurface irrigation (6.5 log unit pathogen reduction) can provide the required 7.0 log unit pathogen reduction for root crops, assuming no contact between the crop and the pathogens in the septic tank effluent[29].

Sewage treatment with primary sedimentation and secondary activated sludge treatment, followed by chemical coagulation, flocculation, filtration and disinfection (chlorination, ozone or ultraviolet radiation) provides >6 log unit pathogen reduction. This level of treatment is used in the United States under California Title 22 Regulations to comply with state water reuse criteria for unrestricted irrigation.

For indirect potable wastewater reuse, additional treatment steps are required, including ultrafiltration (UF) or microfiltration (MF) and reverse osmosis (RO) membrane treatment. Reverse osmosis removes low molecular weight contaminants and total dissolved solids (TDS). Removal of TDS prevents the build-up of salts in the ground water. The very high capital and operating costs, and complexity of this level of treatment, will generally preclude its use in developing countries[30].

Sewage treatment processes, with their corresponding pathogen log unit reductions from WHO guidelines, are shown in Table 5.[31]

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[29] WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 2: Wastewater Use in Agriculture*, p.67.

[30] Ibid., p.66.

[31] Adapted from WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 2: Wastewater Use in Agriculture*, Table 5.2, p.81.

Table 5
WHO treatment processes and pathogen reduction effectiveness

Treatment	Pathogen Removal (Log Unit)			
	Virus	Bacteria	Protozoa	Helminth Eggs
Low Rate Biological Process				
Stabilization Ponds	1 - 4	1 - 6	1 - 4	1 - 3
Constructed Wetlands	1 - 2	0.5 - 3	0.5 - 2	1 - 3
Primary Treatment				
Primary Sedimentation	0 - 1	0 - 1	0 - 1	0 - < 1
Chemically Enanced Primary Treatment	1 - 2	1 - 2	1 - 2	1 - 3
Anaerobic Upflow Sludge Blanket Reactor	0 - 1	0.5 - 1.5	0 - 1	0.5 - 1
Secondary Treatment				
Activated Sludge/Secondary Sedimentation	0 - 2	1 - 2	0 - 1	1 - < 2
Trickling Filters/Secondary Sedimentation	0 - 2	1 - 2	0 - 1	1 - 2
Aerated Lagoon/Settling Pond	1 - 2	1 - 2	0 - 1	1 - 3
Tertiary Treatment				
Coagulation/Flocculation	1 - 3	0 - 1	1 - 3	2
Slow Rate Sand Filtration	1 - 3	0 - 3	0 - 3	1 - 3
Dual Media Filtration	1 - 3	0 - 1	1 - 3	2 - 3
Membranes	2.5 - > 6	3.5 - > 6	> 6	> 3
Disinfection				
Chlorination	1 - 3	2 - 6	0 - 1.5	0 - < 1
Ozonation	3 - 6	2 - 6	1 - 2	0 - 2
Ultraviolet Radiation	1 - > 3	2 - > 4	> 3	0

It is not practical to routinely measure pathogen numbers in raw and treated sewage, so pathogen indicator bacteria, such *E. coli*, are used to monitor the performance of treatment operations.

Table 6 provides WHO verification monitoring levels of *E. coli* that correspond to a target pathogen reduction for different irrigation and agriculture operations[32].

[32] Adapted from WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 2: Wastewater Use in Agriculture*, Table 4.5, p.70.

Table 6
WHO verification monitoring of wastewater treatment

Type of Irrigation	Target Pathogen Reduction (Log Units)	Verification Monitoring Level (*E. coli* /100 ml)	Notes
Unrestricted	4	$\leq 10^3$	Root crops
	3	$\leq 10^4$	Leaf crops
	2	$\leq 10^5$	Drip irrigation of high growing crops
	4	$\leq 10^3$	Drip irrigation of low growing crops
	6 - 7	$\leq 10^1$ to $\leq 10^0$	Level depends on local regulatory agency
Restricted	4	$\leq 10^4$	Labor intensive agriculture practices
	3	$\leq 10^5$	Highly mechanical agricultural practices
	0.5	$\leq 10^6$	Pathogenic removal in septic tank

WHO guidelines, with numerical limits for health-related permissible concentrations of metals in soil irrigated with sewage, are shown in Table 7[33].

Table 7
WHO maximum tolerable soil concentration based on human health protection (metals)

Metal	Maximum Soil Concentration (mg/kg)	Metal	Maximum Soil Concentration (mg/kg)
Antimony	36	Mercury	7
Arsenic	8	Molybdenum	0.6
Barium	302	Nickel	107
Beryllium	0.2	Selenium	6
Flourine	635	Silver	3
Lead	84	Thallium	0.3
		Vanadium	47

There is a recognized potential to transfer harmful pollutants to people via the food chain at soil metal concentrations above these guidelines. Concentrations of metals in irrigated soil will increase with each application of sewage.

In addition to human health considerations, it is also necessary to understand factors that determine success or failure of farm operations that are dependent upon sewage reuse for irrigation. Several factors, including soil-plant-water interactions (irrigation water quality, plant sensitivity and tolerance, soil characteristics, irrigation management practices, and drainage) are important in crop production[34].

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[33] Adapted from WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 2: Wastewater Use in Agriculture*, Table 4.7, p.73.
[34] US Environmental Protection Agency, 2012. *Guidelines for Water Reuse*, EPA/600/R-12/618, pp.3-6.

To assess the suitability of sewage reuse with respect to salinity and trace elements, the Food and Agriculture Organization (FAO) published recommendations for irrigation using degraded water (1985).

Table 8 provides FAO-recommended salinity water criteria[35].

Table 8
FAO-recommended water criteria for irrigation

		Degree of Restriction on Irrigation		
	Units	**None**	**Slight to Moderate**	**Severe**
Salinity				
Ecw *	dS/m	< 0.7	0.7 – 3.0	> 3.0
TDS	mg/L	< 450	450 – 2,000	> 2,000
Specific Ion Toxicity				
Sodium (Na)				
Surface irrigation	SAR **	< 3	3 – 9	> 9
Sprinkler irrigation	meq/l	< 3	> 3	
Chloride (Cl)				
Surface irrigation	meq/l	< 4	4 – 10	> 10
Sprinkler irrigation	meq/l	< 3	> 3	
Boron (B)	mg/L	< 0.7	0.7 – 3.0	> 3.0
Miscelleneous				
Nitrate (NO_3-N)	mg/L	< 5	5 – 30	> 30
Bicarbonate (HCO_3)	meq/L	< 1.5	1.5 – 8.5	> 8.5
pH		6.5 – 8.4		

* ECw = electrical conductivity (deciSiemens/meter)
** SAR = sodium adsorption ratio

Salinity is a key parameter in determining suitability of water used for irrigation. However, the wide variability of soil properties and salinity tolerance in plants confound establishment of generally applicable salinity criteria. Electrical conductivity and sodium absorption ratio are factors used to determine the suitability of water for irrigation. In general, the higher the electrical conductivity and sodium adsorption ratio, the less suitable the water is for irrigation.

All water used for irrigation contains salt to some degree. Water that is reclaimed from sewage tends to have a higher salt concentration than the groundwater or surface water sources from which the water supply is drawn. Accordingly, salts will build up in the soil if it is irrigated with recovered sewage without proper drainage.

[35] Adapted from US Environmental Protection Agency, 2012. *Guidelines for Water Reuse*, EPA/600/R-12/618, Table 3-4, pp.3-7.

Salinity is determined by measuring electrical conductivity (EC), TDS or both in the water; however, for most agricultural measurements, TDS is reported as EC. The use of high-TDS water for irrigation will tend to increase groundwater salinity if it is not properly managed. The extent of salt accumulation in the soil depends on the concentration of salts in the irrigation water and the rate at which salts are removed by leaching[36].

Table 9 provides FAO-recommended trace element water criteria [37] for irrigation.

Table 9
FAO-recommended water criteria for irrigation
(trace elements)

Trace Element	Maximum Concentration (mg/L)	Trace Element	Maximum Concentration (mg/L)
Aluminum	5.0	Iron	5.0
Arsenic	0.1	Lead	5.0
Beryllium	0.1	Lithium	2.5
Boron	0.75	Manganese	0.2
Cadmium	0.0	Molybdenum	0.01
Chromium	0.1	Nickel	0.2
Cobalt	0.1	Selenium	0.02
Copper	0.2	Vanadium	0.1
Fluoride	1.0	Zinc	2.0

The FAO guidelines above provide information that can be used to make an initial assessment for application of sewage reuse for irrigation. There are a number of assumptions in these guidelines that are meant to cover the wide range of conditions that may be encountered in irrigated agriculture practices. These guidelines can be adjusted to more closely address local conditions.

Table 10 outlines USEPA guidelines for sewage reuse practices for irrigation and indirect potable reuse in the United States[38].

[36] US Environmental Protection Agency, 2012. *Guidelines for Water Reuse*, EPA/600/R-12/618, pp.3-6.
[37] Adapted from US Environmental Protection Agency, 2012. *Guidelines for Water Reuse*, EPA/600/R-12/618, Table 3-5, pp.3-9.
[38] Adapted from US Environmental Protection Agency, 2012. *Guidelines for Water Reuse*, EPA/600/R-12/618, Table 4.4, pp.4-9 to pp.4-11.

Table 10
USEPA-suggested guidelines for water reuse

Reuse Category	Level of Treatment	Reclaimed Water Quality
Agriculture		
Food Crops	Secondary *	pH = 6.0 - 9.0
	Filtration **	BOD ≤ 10 mg/l
	Disinfection ***	Turbidity ≤ 2 NTU
		Fecal coliform = No Detect
		Cl_2 residual = 1 mg/l
Agriculture		
Non-Food Crops	Secondary	pH = 6.0 - 9.0
	Disinfection	BOD ≤ 30 mg/l
		TSS ≤ 30 mg/l
		Fecal coliform ≤ 200 CFU/100 ml
		Cl_2 residual = 1 mg/l
Potable Reuse		
Ground Water Recharge	Secondary	pH = 6.5 - 8.5
	Filtration	TOC ≤ 2 mg/l
	Disinfection	Turbidity ≤ 2 NTU
	Advanced Treatment ****	Total coliform = No Detect
		Cl_2 residual = 1 mg/l
		Meet drinking water standards
Potable Reuse		pH = 6.5 - 8.5
Surface Water Recharge	Secondary	TOC ≤ 2 mg/l
	Filtration	Turbidity ≤ 2 NTU
	Disinfection	Total coliform = No Detect
	Advanced Treatment ****	Cl_2 residual = 1 mg/l
		Meet drinking water standards

* Secondary treatment includes activated sludge processes, trickling filters, rotating biological contractors

** Filtration includes filter media (sand and/or anthracite), membrane processes

*** Disinfection includes chlorination ozonation, other chemical disinfectants, UV, membrane processes

**** Advanced treatment includes carbon adsorption, reverse osmosis, advanced oxidation, ion exchange

These guidelines are directed at states that have not developed their own regulations or guidelines for sewage reuse. Conforming to these guidelines is not a criteria for US Agency for International Development (USAID) funding of water projects in other countries. While these guidelines may be useful for other countries, local conditions could limit their applicability.

Sewage reuse in aquaculture

Hazards associated with sewage in aquaculture, based on WHO guidelines, are summarized in Table 11.[39]

Table 11
WHO guidelines – Pathogen hazards from sewage reuse in aquaculture

Hazard	Examples	Health Risk
Bacteria	*Escherichia coli*	Bacteria concentration is always high in fish gut.
	Vibrio cholerae	Cross contamination from gut contents to edible
	Salmonella	flesh during cleaning is the highest risk
	Shigella	
Helminths	*Ascaris*	Risk depends on how the
Soil-transmitted	*Ancylostoma*	wastewater is handled; for example,
	Strongyloides	if shoes are worn by the fish producers.
	Taenia	
	Necator	
Helminths	*Clonorchis*	Food bourne trematodes are a
Trematodes	*Fasciola*	significant health risk in certain limited
	Opisthorchis	geographic areas and require suitable hosts.
	Schistosoma	
Protozoa	*Giardia*	Same comments as for bacteria
	Cryptosporidium	
	Entamoeba	
Viruses	*Hepatitis*	Same comments as for bacteria
	Adenovirus,	
	Rotavirus	
	Norovirus	

WHO has developed health-based targets that establish a defined level of health protection for a given exposure to these hazards. Targets based on a measure of the disease include disability adjusted life year (DALY) and absence of a specific disease related to exposure.

After health targets have been defined, a combination of health-protection measures to achieve these targets is specified – for example, sewage treatment, food handling and preparation methods, timing of wastewater application, and health and hygiene

[39] Adapted from WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 3: Wastewater Use in Aquaculture*, Table 2.2, pp.16.

practices.[40] The reference level of risk as a health-based target for protecting consumers of sewage-fed aquaculture products is ≤10^{-6} DALY per person per year[41].

Table 12 presents WHO microbial reduction targets that can be used to facilitate compliance with health-based targets for food-borne trematodes[42].

Table 12
WHO health-based targets for aquaculture wastewater use

Media	**Microbial Reduction Target**		**Verification Monitoring**
	Viable trematode eggs * (# per 100 ml)	**Helminth eggs (# per liter)**	**(viral, bacterial, protozoan) (*E. coli* /100 ml) *****
Consumers			
Pond Water	Not detectable	≤ 1	≤ 10^{4}
Wastewater	Not detectable	≤ 1	≤ 10^{5}
Edible Fish Flesh	Not detectable **	Not detectable	
Producers			
Pond Water	Not detectable	≤ 1	≤ 10^{3}
Wastewater	Not detectable	≤ 1	≤ 10^{4}

* Include schistosome eggs where relevant

** Metacercariae (encysted larva on an aquatic intermediate host)

*** Corresponds to ≤ 10^{-6} DALY per person per year

A microbial water-quality target of ≤10^4 *E. coli* per 100ml of pond water has been established to protect product consumers. A microbial quality target has been set at ≤10^5 *E. coli* per 100ml for wastewater directed to account for dilution of the wastewater after entering the aquaculture pond. For protection of the aquaculture workers, the microbial water quality for pond water has been set at ≤10^3 *E. coli* per 100ml [43].

USEPA guidelines for sewage sludge

Under the Clean Water Act (CWA) Amendments of 1987, the USEPA developed regulations to protect public health and the environment from any reasonably anticipated adverse effect that might be present in sewage sludge.

These regulations, published February 1993 as Title 40 CFR (Code of Federal Regulations), Part 503, '*Standards for the Use or Disposal of Sewage Sludge*' set general requirements, pollutant limits, management practices and operational standards for final use or disposal of sewage sludge generated during treatment of domestic sewage in a treatment works. CFR Title 40 Part 503 includes five subparts: (1) General Provisions, along with requirements for (2) Land Application, (3) Surface Disposal, (4)

[40] Adapted from WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 3: Wastewater Use in Aquaculture*, Table 5.1, p.47.
[41] WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 3: Wastewater Use in Aquaculture*, p.40.
[42] Adapted from WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 3: Wastewater Use in Aquaculture*, Table 4.1, p.41.
[43] WHO, 2006. *Guidelines for Safe Use of Wastewater, Excreta and Greywater, Volume 3: Wastewater Use in Aquaculture*, p.42.

Pathogen/Vector Attraction Reduction, and (5) Incineration. These regulations do not establish requirements for the use or disposal of sludge generated at industrial facilities during treatment of industrial wastewater, including sewage sludge generated during treatment of industrial wastewater combined with domestic sewage[44].

Title 40 CFR Part 503 Subpart B – Requirement for Land Application, specifies requirements for applying biosolids to land to take advantage of the nutrient content or soil conditioning properties of the biosolid. These rules apply to materials derived from biosolids, including biosolids that have undergone treatment or been mixed with other materials.

If bulk sewage sludge is applied to agricultural land, either the cumulative loading rate for each pollutant must not exceed the cumulative pollutant loading rate for each pollutant or the concentration of each pollutant in the sewage sludge must not exceed the concentration for each pollutant – as shown in Table 13 [45].

Table 13
USEPA bulk sewage pollution loading limits

Pollutant	Cumulative Loading Rate (kg/hectare)	Monthly Average Concentration (mg/kg*)
Arsenic	41	41
Cadmium	39	39
Copper	1,500	1,500
Lead	300	300
Mercury	17	17
Nickel	420	420
Selenium	100	100
Zinc	2,800	2,800
* Dry weight basis		

In order to maintain agronomically appropriate nutrient loading and avoid contamination of groundwater and environmental damage from nitrogen run-off and associated harmful algal blooms, the annual application rate for domestic septage applied to agricultural land should not exceed the rate calculated using Equation 1 [46]:

$$AAR = \frac{N}{0.0026} \quad \text{..................... Equation 1}$$

Where:

AAR = annual application rate (gals/acre/year)

N = amount of nitrogen needed by crops grown on the land (lbs/acre/year)

[44] Title 40 CFR 503, Subpart A, Section §503.6, Exclusions, (d).
[45] Adapted from Title 40 CFR 503, Subpart B, §503.13 – Table 2: Cumulative Pollutant Loading Rates and Table 3: Pollutant Concentrations.
[46] EPA, September 1993. *Domestic Septage Regulatory Guidance, A Guide to The EPA 503 Rule*, EPA 832-B-92-005, p.22.

Title 40 CFR Part 503 Subpart D – Pathogens and Vector Attraction Reduction, describes alternatives to reduce pathogens in biosolids and potential for biosolids vector attraction. Biosolids are designated as 'Class A' or 'Class B' depending on pathogen concentration. Requirements for land application vary depending on the biosolid class.

Class A biosolids can have no detectible levels of pathogens, including *Salmonella*, enteric viruses or viable helminth ova. In general, Class A biosolids that meet vector attraction reduction requirements and low level metals content can be used in small quantities by the general public without buffer requirements or crop type, crop harvesting or site access restrictions. Bulk use of Class A biosolids is subject to buffer requirements, but not crop harvesting restrictions[47].

Class B biosolids are treated, but still contain detectible levels of pathogens that do not pose a threat to public health or the environment as long as actions are taken that avoid inappropriate exposure to the biosolids by buffer requirements and crop type, crop harvesting and site access restrictions[48].

Pathogen reduction requirements under CFR Title 40 Part 503 can be met using certain specified alternatives to treat the biosolids or by showing that the biosolids meet certain quality requirements. The following six (6) alternatives for treating biosolids are specified to meet Class A classification with respect to pathogens[49]:

Alternative 1 – Thermal treatment

Alternative 2 – High pH/High temperature

Alternative 3 – Other known processes

Alternative 4 – Other unknown processes

Alternative 5 – Processes that further reduce pathogens (PFRP)

Alternative 6 – Equivalent PFRP

For all of the above Class A pathogen alternatives, either the density of faecal coliform in the biosolids must be less than 1,000 MPN (most probable number) per gram of total solids (dry weight basis) or the density of *Salmonella* bacteria in the biosolids must be less than 3 MPN per 4 grams of total solids (dry weight basis).

Appendix 2 lists the analytical methods that have been identified by USEPA to confirm treatment conformance to CFR Title 40 Part 503 regulations.

Pathogen reduction must take place before or at the same time as vector attraction reduction is achieved as described, except when the pH adjustment, per cent solids vector attraction, injection or incorporation options are met[50].

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[47] *EPA Water: Sewage Sludge Biosolids, Frequently Asked Questions*. Available at: http://water.epa.gov/polwaste/wastewater/ treatment/biosolids/genqa.cfm
[48] Ibid.
[49] Title 40 CFR 503, Subpart D, Section §503.32, Pathogens.
[50] Ibid.

Alternative 1 – Thermal treatment

Alternative 1 provides that following four (4) alternative thermal treatment methods to reduce pathogens involving heating duration and temperatures to meet Class A biosolids, which take into consideration the solids-liquid nature of the biosolids along with the particle size and the method through which the heat is brought into contact with the biosolids[51].

When the percentage solids of the sewage sludge is greater than 7 per cent, the temperature of the sewage sludge shall be 50^{o}C or higher for a time period of 20 minutes or longer, with the required temperature and time period determined using the following Equation 2:

$$D = \frac{131{,}700{,}000}{10^{0.14t}} \text{ .... Equation 2}$$

Where:

D = time (days)

t = temperature (^{o}C)

For example, for a biosolid that contains 10 per cent solids that is heated to 80^{o}C, the required time to achieve Class A biosolids calculated by Equation 2 is less than 1 minute – but under the regulations must be at least 20 minutes to account for assumed heating inefficiencies.

$$D = \frac{131{,}700{,}000}{10^{0.14(80)}} = \frac{131{,}700{,}000}{251{,}000{,}000{,}000} = 0.75 \text{ minutes}$$

When the percentage solids of the sewage sludge is greater than 7 per cent and small particles of sewage sludge are heated by either warmed gas or an immiscible liquid, the temperature of the sewage sludge shall be 50^{o}C or higher for a time period of 15 seconds or longer, with the required temperature and time period determined using Equation 2.

When the percentage solids of the sewage sludge is less than 7 per cent and the time period is at least 15 seconds, but less than 30 minutes, the required temperature and time period is determined using Equation 2.

$$D = \frac{131{,}700{,}000}{10^{0.14(80)}} = \frac{131{,}700{,}000}{251{,}000{,}000{,}000} = 0.75 \text{ minutes}$$

When the percentage solids of the sewage sludge is less than 7 per cent, the temperature of the sludge is 50^{o}C or higher and the time period is 30 minutes or longer, the required temperature and time period is determined using the following Equation 3:

$$D = \frac{50{,}070{,}000}{10^{0.14t}} \text{ .... Equation 3}$$

[51] Ibid.

For example, for a biosolid that contains 7 per cent solids that is heated to 80°C, the required time to achieve Class A biosolids calculated by Equation 2 is less than 1 minute – but under the regulations must be at least 30 minutes to account for assumed heating inefficiencies.

$$D = \frac{50{,}070{,}000}{10^{0.14(80)}} = \frac{50{,}070{,}000}{158{,}000{,}000{,}000} = 0.45 \text{ minutes}$$

Alternative 2 – High pH/High temperature

Process conditions that are considered effective to reduce pathogens below detection levels include elevating pH to 12 for 72 hours or longer, maintaining the temperature above 52°C for at least 12 hours and air drying to more than 50 per cent solids.

Alternative 3 – Other known processes

Alternative 3 requires comprehensive monitoring of enteric viruses and helminth ova during the demonstration of new processes to confirm that such process meet Class A pathogen requirements. New processes must be shown to reduce the density of enteric viruses and viable helminth ova in the biosolids to less than 1 PFC per 4 grams total solids and less than 1 per 4 grams total solids, respectively.

Once a new process has been shown to achieve the required pathogen reduction, the process must be monitored and shown to be operated under the same conditions that were used during the demonstration. In this case, additional pathogen analysis of the treated biosolids is not required.

Alternative 4 – Other unknown processes

Alternative 4 is used in situations where the upstream biosolids treatment process is not known or the biosolids were treated in a process under less stringent conditions than those under which the biosolids achieved Class A qualification.

For this alternative, the density of both enteric viruses and viable helminth ova in the treated biosolid must be reduced to <1 PFC per 4 grams total solids. Unlike Alternative 3, each batch of biosolid treated under Alternative 4 must be analysed rather than just monitored for operating conditions.

Alternative 5 – Processes that further reduce pathogens (PFRP)

- Composting:
  Within vessel or static aerated pile method. Maintain biosolids at 55°C or higher for 3 days.

- Heat drying:
  Direct or indirect contact with hot gases to reduce moisture content of biosolids to less than 10 per cent, with the biosolids' temperature greater than 80°C.

- Heat treatment:
  Liquid biosolids heated to a temperature of 180°C or higher for 30 minutes.

- Thermophilic aerobic digestion:
  Liquid biosolids agitated with air to maintain aerobic conditions, with a residence time of 10 days at 55^{o}C to 60^{o}C.

- Beta ray irradiation:
  Biosolids irradiated with beta rays from an accelerator at dosages of at least 1.0 megarad at room temperature.

- Gamma ray irradiation:
  Biosolids irradiated with gamma rays from certain isotopes (cobalt 60, caesium 137) at room temperature.

- Pasteurization:
  The temperature of the biosolids is maintained at 70^{o}C or higher for 30 minutes or longer.

One of the following vector attraction reduction requirements below must be met when bulk sewage sludge is applied to agricultural land. These requirements are designed to reduce the attractiveness of the biosolids to vectors or to prevent vectors from coming into contact with the biosolids[52].

Option 1 - Meet 38 per cent reduction in volatile solids content

Option 2 - Demonstrate vector attraction reduction with additional anaerobic digestion in a bench scale unit

Option 3 - Demonstrate vector attraction reduction with additional anaerobic digestion in a bench scale unit

Option 4 - Meet a specific oxygen uptake rate for aerobically digested biosolids

Option 5 - Use aerobic processes at greater than 40^{o}C for 14 days or longer

Option 6 - Alkali addition under specified conditions

Option 7 - Dry biosolids with no unstabilized solids to at least 75 per cent solids

Option 8 - Dry biosolids with unstabilized solids to at least 90 per cent solids

Option 9 - Inject biosolids beneath the soil surface

Option 10 - Incorporate biosolids into the soil within 6 hours of application to or placement on the land

Option 11 - Cover biosolids placed on a surface disposal site with soil or other material at the end of each operating day (only for surface disposal)

Option 12 - Alkaline treatment of domestic septage to pH12 or above for 30 minutes without adding more alkaline material

[52] Title 40 CFR 503, Subpart D, §503.33, Vector attraction reduction.

Appendix 1
Guidelines for Use of Wastewater, Excreta and Greywater

World Health Organization (WHO)

1973
Reuse of Effluents: Methods of Wastewater Treatment and Public Health Safeguards
Provided guidance on the use of wastewater and excreta in agriculture and aquaculture, while protecting public health.

1989
Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture
Provided a review of epidemiological studies and other information to offer guidance on technical standards and policy for the use of wastewater and excreta in agriculture and aquaculture.

2006
Guideline for the Safe Use of Wastewater, Excreta and Greywater
Volume 1: Policy and regulatory aspects.
Volume 2: Wastewater use in agriculture.
Volume 3: Wastewater and excreta use in aquaculture.
Volume 4:Excreta and greywater use in agriculture.

Provided updated information on new scientific evidence concerning pathogens, chemicals and other factors, taking into account risk assessment and epidemiological data.

US Environmental Protection Agency (EPA)

1980 (1st publication)
Guidelines for Water Reuse

1992 (updated publication)
Guidelines for Water Reuse

2004 (updated publication)
Guidelines for Water Reuse

2012
Guidelines for Water Reuse
Provides updated details about the range of reuse applications and concepts and treatment technologies supporting water reuse operations.

Appendix 2
USEPA Standard Analytical Methods
40 CFR 503, Subpart A, Section 503.8, Sampling and Analysis

A. Standard methods for testing pathogenic indicators

(1) *Enteric viruses.* ASTM Designation: D 4994-89, 'Standard Practice for Recovery of Viruses From Wastewater Sludges', 1992 Annual Book of ASTM Standards: Section 11—Water and Environmental Technology, ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

(2) *Faecal coliform.* Part 9221 E. or Part 9222 D., 'Standard Methods for the Examination of Water and Wastewater', 18th Edition, 1992, American Public Health Association, 1015 15th Street, NW, Washington, DC 20005.

(3) *Helminth ova.* Yanko, W.A., 'Occurrence of Pathogens in Distribution and Marketing Municipal Sludges', EPA 600/1-87-014, 1987. National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 (PB 88-154273/AS).

(4) *Salmonella sp. bacteria*. Part 9260 D., 'Standard Methods for the Examination of Water and Wastewater', 18th Edition, 1992, American Public Health Association, 1015 15th Street, NW, Washington, DC 20005; or Kenner, B.A. and H.P. Clark, 'Detection and enumeration of *Salmonella* and *Pseudomonas aeruginosa*', *Journal of the Water Pollution Control Federation*, Vol. 46, No. 9, September 1974, pp.2163-2171. Water Environment Federation, 601 Wythe Street, Alexandria, Virginia 22314.

B. Standard methods for solids, inorganic pollutants, metals, oxygen uptake rate

(1) *Total, fixed, and volatile solids.* Part 2540 G., 'Standard Methods for the Examination of Water and Wastewater', 18th Edition, 1992, American Public Health Association, 1015 15th Street, NW, Washington, DC 20005.

(2) *Inorganic pollutants.* 'Test Methods for Evaluating Solid Waste, Physical/Chemical Methods', EPA Publication SW-846, Second Edition, 1982, with Updates I, April 1984, and II, April 1985, and Third Edition, November 1986, with Revision I, December 1987.

(3) *Specific oxygen uptake rate*. Part 2710 B., 'Standard Methods for the Examination of Water and Wastewater', 18th Edition, 1992, American Public Health Association, 1015 15th Street, NW, Washington, DC 20005.

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Knowledge and research: Knowledge is central to progress. It is not just the generation of new knowledge through research, but using existing knowledge to the full, and working seriously on dissemination and uptake.

WEDC: Water, Engineering and Development Centre
School of Civil and Building Engineering
The John Pickford Building
Loughborough University
Leicestershire LE11 3TU
United Kingdom

T: +44 (0)1509 222885 F: +44 (0)1509 211079
E: wedc@lboro.ac.uk W: http://wedc.lboro.ac.uk

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Loughborough University