WASTEWATER TREATMENT: WHERE DO TOILET & SINK WASTES GO?

John D. Halfman
Hobart and William Smith Colleges
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Wastewater treatment is a multibillion dollar, and typically behind the scenes, industry. US law dictates that water used and degraded by rural and municipal users must be treated before it is released back into the environment, i.e., typically to a nearby stream, lake or ocean. Treatment processes are designed to remove the organic matter from the waste stream, including the organic matter from garbage, food preparation, cleaning clothes and dishes, and human wastes. Treating this waste stream is paramount because raw sewage contains fecal coliform bacteria and other potentially disease causing micro-organisms within human feces (e.g., *Escherichia coli* and *Streptococcus faecalis* bacteria and protozoans like *Cryptosporidium*), and provides a fertile breeding ground for other micro-organisms that if ingested may cause dysentery, typhoid and/or cholera. Even though the US is a world leader in treatment of wastewaters, the EPA estimates that 1.5 million people become ill each year in the US from infections caused by fecal contamination.

Raw sewage also stimulates the consumption of dissolved oxygen in nearby waterways, and in sufficient quantities, transforms the waterway into a smelly, stinky, anoxic cesspool. The amount of organic loading is typically measured by the biological oxygen demand (BOD). The raw sewage stimulates the natural decomposition of the organics by micro-organisms, mainly bacteria. The process removes oxygen dissolved in the water because bacterial use of oxygen for respiration is faster than natural mechanisms to replace it, like diffusion from the atmosphere. Sufficient oxygen is critical for all respiring organisms including crawfish, clams, and fish. Each organism has its own threshold, minimum concentration necessary for survival. If the supply of raw sewage is sufficient, bacterial uptake turns streams, lakes and ocean coastlines anoxic. Once anoxic, the decomposition of any remaining organic matter continues by anaerobic bacteria instead of aerobic bacteria. The transformation is an unwelcomed substitute due to the release of hydrogen sulfide (rotten egg / swamp gas smell, H_2S) or methane (CH_4) by the anoxic bacteria instead of carbon dioxide (CO_2) and water (H_20) by aerobic bacteria.

In streams, oxygen depletion occurs downstream from the wastewater's point of entry and characteristically defines an oxygen sag curve and benthic critter assemblages (Fig. 1). Bacteria decompose the organic wastes and deplete oxygen concentrations to its lowest concentrations farther downstream than the point of entry. The distance downstream is proportional to the supply (amount and rate) of organic matter and other physical, biological and chemical factors like water temperature, water turbulence, the diffusion of oxygen from the atmosphere and photosynthetic activity. If only one source of raw sewage exists, then the oxygen depletion recovers farther downstream, the removal of oxygen by bacteria declines as the raw organic matter is decomposed, and is offset by the addition of oxygen by diffusion from the atmosphere and photosynthesis. Successive point sources of raw sewage however, create a series of successive and overlapping oxygen sag curves that can deoxygenate a stream for many miles.

In lakes, the depletion of oxygen is typically confined to the bottom waters of the lake. Lakes are typically stratified in the summer season with warmer, less dense, sunlit, surface water (epilimnion), that is warmed by the summer sun, “floating” above colder (typically 4ºC or 39ºF), more dense, dark, bottom water (hypolimnion). The seasonal stratification physically isolates the hypolimnion from epilimnetic oxygen replacement mechanisms like photosynthesis and diffusion from the atmosphere. Therefore, the hypolimnion can turn anoxic when aerobic bacteria are supplied with sufficient quantity of organic matter and the oxygen is not naturally replaced until fall turnover. The seasonal stratification and potential hypolimnetic anoxia breaks down during fall overturn, when the surface waters cool to 4ºC. Density no longer stratifies the water column, the entire lake circulates vertically, and exposes the entire lake to atmospheric oxygen.

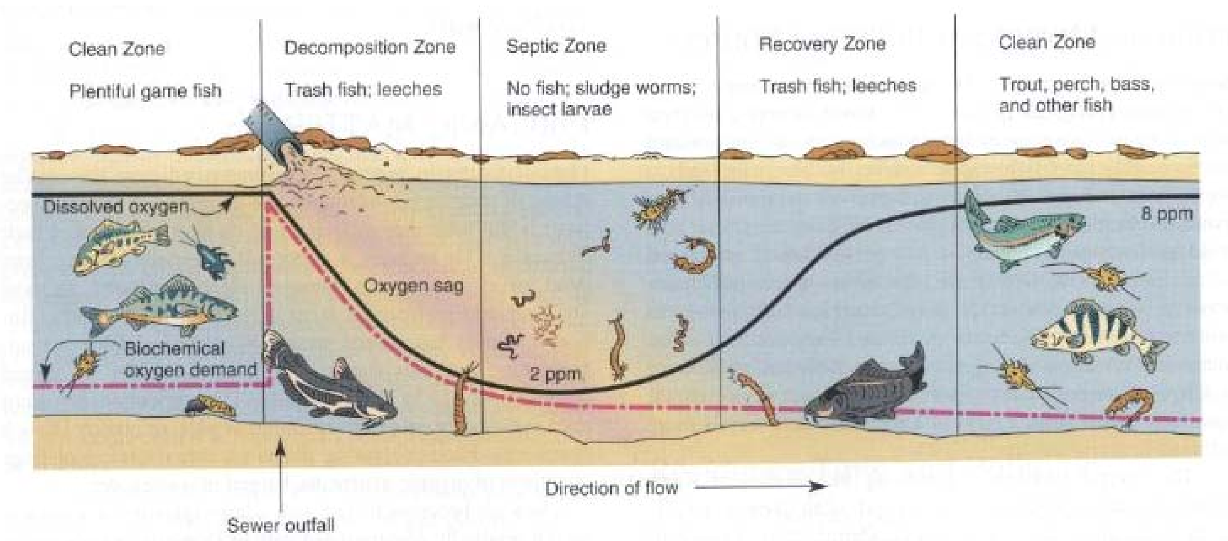

Fig. 1. A typical oxygen sag curve downstream from a sewage outfall (organic-matter input), and its impact on both dissolved oxygen and the fauna in the stream (After Montgomery, 2008).

Raw sewage also stimulates eutrophication of the nearby stream, lake or ocean. Bacterial decomposition of the organic matter releases nutrients, namely nitrates and phosphates, back into the aquatic environment. These extra nutrients “fertilize” additional algal and other plant growth, and the eutrophication process transforms the waterway into more a productive state. When these plants die, continued nutrient recycling promotes persistent and continued algal growth. If severe enough, the continual decomposition of dead algae turns the water anoxic, and the waterway becomes eutrophic. The algal blooms associated with eutrophic systems, are typically slimy blue-green algae that float at or near the water’s surface further degrading the water quality. Excess nitrates are also a health risk to humans, specifically methemoglobinemia or blue-baby syndrome. The EPA sets a maximum contaminant level (MCL) for nitrate concentrations at 10 mg/L for safe drinking water (see Table 1 for other MCL examples).

Wastewater treatment therefore, is designed to avoid these organic-based sewage disposal problems. Organic-rich wastewater is treated by septic or other on-site systems in rural areas, or collected by sewer systems and treated by municipal wastewater treatment facilities in larger communities. Both are use in the Finger Lakes region.

Septic-Tank Wastewater Treatment

Onsite septic-tank wastewater treatment continues to serve at least 30% of the US population, or approximately 22 million locations with 0.5 million added annually. Even though municipal wastewater treatment facilities are more effective than onsite methods, construction of adequate municipal systems rarely keeps pace with population growth and urban sprawl. In the Finger Lakes region, larger cities like Rochester and Syracuse plus smaller cities and villages like Geneva, Penn Yan or Watkins Glen are served by sewer systems and municipal wastewater treatment facilities. Sewer systems are also found along the margins of some of the lakes including Honeoye, Keuka, and portions of Canandaigua, Seneca, and Skaneateles Lakes to reduce the threats to these water bodies. The remaining rural and larger segment of the region's population however is served by onsite systems.

Septic systems treat organic wastes in two stages, first in the septic tank and then the absorption field or dry well (Fig. 2). Wastewater from the home or small business first encounters the septic tank where solids settle to the bottom of the tank. These solids are slowly digested by bacterial action into a more liquefied state. The liquid wastewater discharges from the tank into an absorption field of shallow perforated pipes positioned parallel to each other on a gravel-base which are then buried beneath the surface. The "dry well" is a large-diameter, deep, typically gravel-filled, well. The liquid wastewater is allowed to seep into the nearby soil where aerobic microbes (bacteria and fungi) respire and decompose the remaining dissolved organic material from the wastewater. Sufficient atmospheric oxygen is available when the absorption field is near the ground surface. If the discharge is buried too deeply, then saturated soils could turn anoxic, and anaerobic bacteria may emit foul smells. Passage through the soil, especially if it is fine-grained, also filters the liquid, removing fine suspended solids and large pathogenic organisms. Ideally, the liquid is purified of any contaminants before it joins nearby surface water or groundwater.

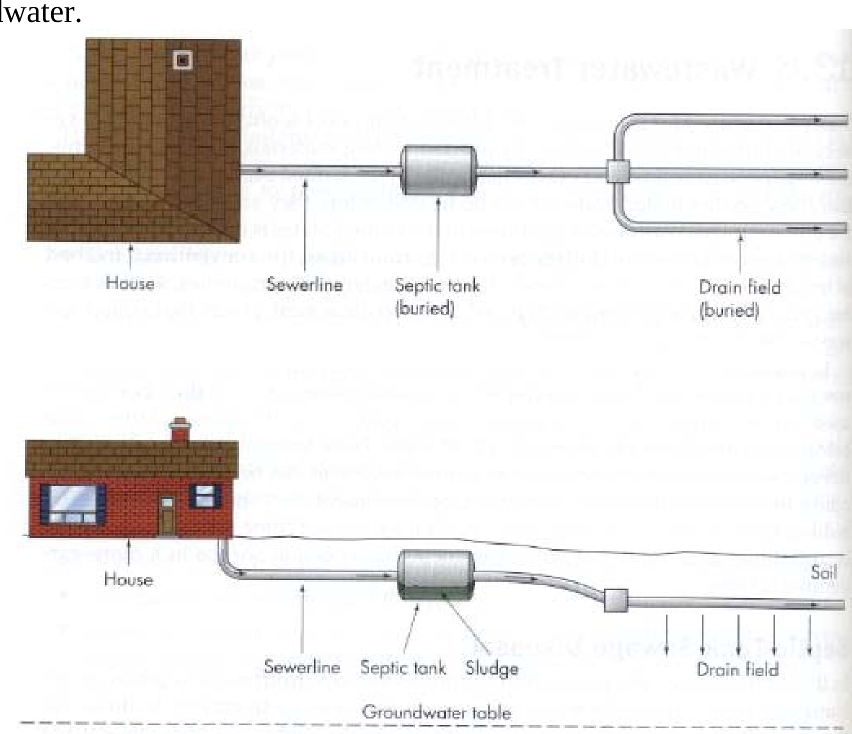

Fig. 2. Onsite sewage disposal system for a rural home (after Keller, 2008).

A septic system has specific geologic and other requirements to function properly. The soil must be sufficiently permeable to allow the passage of the fluids or the wastes will back up into the house. However, the soil cannot be so permeable that fluid flow is too rapid for proper bacterial decomposition and filtration. The absorption field must be sited sufficiently distant from nearby surface water, groundwater, well(s), and the soil and bedrock surfaces to enable adequate space for treatment. The system's size must also be large enough to insure adequate space for the amount of fluids dumped down the drain, and the size is typically determined by the number of bedrooms (up to 15-m^2 or 160-ft^2/bedroom, or 1 acre/house, depending on soil permeability).

New York State Appendix 75-A outlines the state requirements for septic systems, with some local programs providing more stringent requirements for such watersheds as Canandaigua or Keuka Lakes. These requirements also dictate that many areas in the Finger Lakes region are unsuitable for septic absorption fields because the lot is too small, on too steep a slope, too close to nearby water resources (lake, groundwater, well), or the soils are too fine- (or too coarse-) grained, especially where a potential and/or existing building is sandwiched on a postage-stamp lot between the lakeshore and a steep cliff, a lake-side road or railroad. In such cases, where possible, alternative systems may be feasible. Remember, properly functioning septic systems prevent the release of untreated organic wastes to the environment, which reduces the biological oxygen demand, eutrophication of our waterways, and various disease causing vectors. To avoid these problems and other pitfalls, septic systems must therefore be designed and approved by a licensed sanitary/environmental engineer in New York State before code officers or watershed inspectors can issue a building permit for renovations and/or new construction.

A few more problems exist however, some which can be reduced by good household management and maintenance of the system. Not all of the solid organics trapped in septic tanks are decomposed and liquefied by bacteria. Thus, the volume of organic sludge accumulates over time and slowly fills the tank. Once full, the smelly (hydrogen sulfide, H_2S) raw sewage enters and impedes the proper function of the absorption field. Thus, the organic sludge in each septic tank should be pumped out every 3 to 5 years to prevent solid organics from entering the soil. The sludge is typically transported to a municipal facility for treatment. Septic systems rarely treat toxic or radioactive chemicals, heavy metals, oils, paints, fertilizers, pesticides, birth control medication, antibiotics, and other prescription drugs. To prevent their release to the environment, they should not be dumped down the drain and instead should be brought to hazardous waste collection centers. More importantly, some household chemicals like bleach can kill the microorganisms that decompose the organic wastes rendering the system less or in some cases completely ineffective. The decomposition of the organic wastes also releases nutrients, phosphates and nitrates, into the soil. The dissolved phosphates are likely to bind to soil particles, are utilized by "greener" plants, and do not travel far. Nitrates however, are water soluble and are easily transported to nearby surface water and/or groundwater systems.

Municipal Wastewater Treatment

Municipal wastewater treatment facilities typically serve urban communities, locations with a high enough population density to prevent effective treatment by individual septic systems, or regions where the geology, land use, and/or proximity to streams and lakes prevent adequate service by septic systems, and warrant the additional expense. Over 75% of the US population is now served by sewer systems, and untreated wastewater is released into the environment in only

5% of these cases. Municipal facilities treat organic waste through primary, secondary and in some cases tertiary steps (Fig. 3).

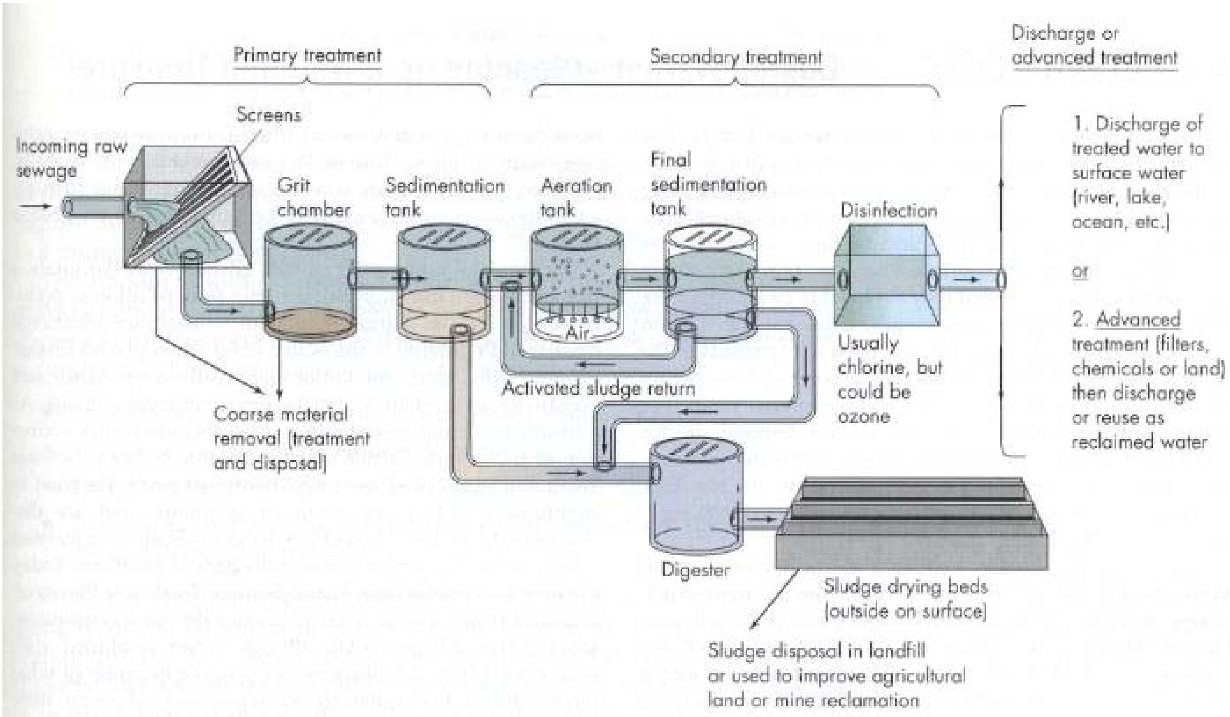

Fig. 3. Idealized diagram for a municipal wastewater treatment system without any tertiary (advanced) treatment (after Keller, 2008).

Primary treatment utilizes a number of physical processes that collectively separate larges pieces of solid waste and other specialty items from the remaining effluent. For example, screens remove large floating objects like branches, dead animals and floating trash. Settling chambers remove sand, gravel and larger inorganic and organic materials from the effluent stream by allowing these larger and denser particles to settle to the bottom of the chamber. Skimmers remove substances like oil, grease and similar floating liquids. Primary treatment typically removes 30 to 40% of the organic pollutants from the wastewater. These separated materials are either treated individually or, more typically, sent to a landfill, and the effluent is passed on to secondary treatments.

Secondary treatment is primarily biological. Aerobic microbes (bacteria and fungi) decompose and respire the dissolved and suspended organic material not removed by the primary treatment. The microbes effectively break down the bulk of the organic materials, reduce the biological oxygen demand, clarify the effluent, and release nutrients to the remaining effluent. The process takes place in large tanks that are continually aerated to supply the necessary oxygen to the aerobic bacteria. The remaining solids settle in a second tank, and the accumulating sludge is recycled back into the beginning of the secondary waste stream for further decomposition, sent to a landfill or sent to an onsite anaerobic digester to generate methane and provide energy for the plant's operations (see more options below). The remaining, clarified, effluent is then typically released to the environment, a nearby stream, lake or ocean. Combined, primary and secondary treatments remove approximately 90% of the suspended solids and biological oxygen demand, and roughly 50% of the nitrogen and 30% of the phosphates from the effluent.

Tertiary treatment, when utilized, combines a host of unrelated filtration, chemical processes and occasionally nature to remove nutrients, heavy metals, and/or other specific compounds not touched by primary and secondary treatments. For example, passage through activated charcoal or other permeable membranes, and/or chemical precipitation of dissolved materials to remove the precipitates in settling tanks, can purify the effluent sufficiently to be used as drinking water although it is more commonly used for irrigation or livestock purposes, especially where water resources become scarcer in this country. Other facilities will use ozone or ultraviolet light to disinfect the effluent before releasing it into the environment. Tertiary treatments are more expensive than primary and secondary processes, and typically not required by law. As a consequence, only 2% of the US population is served by facilities with tertiary treatment, especially in communities where water scarcity compels water recycling.

The facilities need to dispose of the sludge, the remaining organic soup that settles out from the secondary treatment, and its disposal accounts for 25 to 50% of the operating cost of the plant. Typically the sludge is dried (to reduce the mass and volume), disinfected and stabilized, and trucked to a landfill. Landfills charge by the ton, generate their own environmental and other aesthetic problems, and are closing around the country. Other options for sludge disposal include its conversion to a money making product. For example, sludge can be used as a fertilizer or compost material, turning previous disturbed land by strip mining or poor soil conservation into more productive land. However, the material must be carefully monitored because it may contain high concentrations of heavy metals or other toxic industrial chemicals. Other facilities have experimented with converting the sludge into bricks, concrete blocks or using the organics as feedstock for incineration. Alternatively and more commonly, sludge is sent to an anaerobic digester, where anaerobic bacteria continue to decompose the organic matter and create methane or natural gas (CH_4) in the oxygen-poor chamber. The generated methane fuels the facility, and/or is sold locally as natural gas. The remaining smaller pile of sludge is then disposed in a landfill (or elsewhere).

Municipal wastewater treatment facilities face numerous hurdles (problems). Large amounts of rainwater or snow melt can “flood” the system and overload its capacity when storm drains and municipal waste utilize a combined sewer system. When flood waters exceed the facility’s capacity, then raw sewage is released to the environment. Many communities have separated the storm-runoff from the municipal waste sewers to remove this problem but dual sewer lines significantly increase installation and maintenance costs, and thus local taxes.

The effluent from secondary treatment discharges nutrients to the environment. The nutrient loading was significantly worse when detergents and soaps contained phosphates. The cleansing molecule is designed to separate the dirt and grease from dishes or clothes, and easily dissolves in water at one end, and dissolved dirt and/or grease at the other. When the molecule is washed away, the dirt and/or grease washes away as well. Before the mid-1900s, phosphates were commonly a part of the molecule. These phosphates when released to the environment contributed to the eutrophication of neighboring waterways. For example, it was partly responsible for the eutrophication of the lower Laurentian Great Lakes in the 1960s and 1970s. Since the early 1990s, most manufacturers of detergents and soaps have found substitutes for phosphorus. In addition, some facilities add chemicals (e.g., iron compound) to the effluent that precipitates and removes phosphates from the waste stream to reduce the nutrient loading.

Finally, the nutrients and other fine particulates in the effluent can be effectively “cleansed” by wetlands. The thick growth of plants provides an ideal place to filter fine suspended materials, and assimilate the nutrients.

The effluent is also routinely chlorinated to disinfect the microbes in the effluent. However, the safety of chlorination has recently been questioned because the chlorine can combine with numerous organic compounds and create chlorinated hydrocarbons like chloroform, and some chlorinated hydrocarbons are carcinogenic. Here, chlorination’s importance for disinfecting the microbes most likely outweighs the dangers from creating the chlorinated hydrocarbons. Ozone is another, but more expensive, means to disinfect the effluent before it is released to the environment.

Industry may dump chemical (acids, bases, heavy metals, organic compounds, etc.) and/or thermal wastes into the municipal sewer system if permits allow this. The laundry list of chemicals created as by-products of industrial processes provides a challenge if the treatment is performed by the facility because some chemicals may negatively impact the primary and secondary processes, e.g., strong oxidizers can kill the microorganisms, and typically each chemical has unique treatment methods. For example, acids and bases require neutralization. Organic compounds can be biodegraded if their biopersistence is low. Volatile compounds can be removed by air stripping as they volatilize quickly in air, and then collected and treated separately. Many carbon compounds are removed by activated carbon filters. Spent activated carbon can then be sent to a landfill or cleaned and reused. Other chemicals can be precipitated into flocs by adding specific reactants, are collected by filtration or settling and sent to a hazardous waste landfill. The complexity indicates that the preferred strategy is pretreatment of industrial wastes before it reaches wastewater treatment facility. Alternatively, the industrial wastes may meet the EPA’s MCLs when mixed with and diluted by the normal waste stream, and thus sent onward to the nearby waterway.

In 2000, the US Geological Survey reported that they detected low concentrations of many common-household, agricultural and industrial compounds including caffeine, cholesterol, coprostanol (by-product of DEET), human and veterinarian drugs, antibiotics, natural and synthetic hormones, detergent metabolites (by-products), plasticizers, insecticides, pesticides, and fire retardants. Many of these compounds are found on supermarket shelves and every household medicine cabinet and/or broom closet. It indicates that septic systems and wastewater treatment facilities, designed in the 1950’s before these compounds were present in the waste stream, do not now adequately remove them, and should be redesigned or modified to remove them. Recent toxicology research also suggests that persistent exposure to low concentrations of these compounds, concentrations below the EPA’s published MCLs, still have adverse impacts. These findings are disturbing. Hopefully, methods will be found to effectively and economically remove these “new” compounds before they enter the environment.

Finally, the current approach to both solid and liquid waste management in the US is to “treat” everything that we throw away, as cheaply and as safely as possible. For example, removing the last few parts per million of some materials from the effluent may not significantly improve water quality. This is especially true, if the concentration of these chemicals is below the EPA’s MCLs, assuming that published MCLs are a good threshold for safe drinking water. The current philosophy forces facilities to treat everything we generate, and in some instances the facilities fail due to their antiquated design. Other options exist. The best option will find ways to reduce the amount and variety of wastes generated at the source. This can be accomplished by reusing, recycling, and/or more importantly eliminating the generation of many wastes before treatment and disposal becomes necessary. Therefore, homeowners should consider a number of common sense approaches to meet these goals:

- Many household compounds are toxic. You should select less toxic or non toxic alternatives whenever possible.
- Use these chemicals wisely. Purchase them in the amounts required and apply them as directed. More is not better.
- Take unwanted chemicals to hazardous waste collection centers. Do not pour them down the drain or throw them into the trash.
- Never pour unused or unwanted chemicals on the ground. Soil and treatment facility microbes may not destroy and in fact may be killed by these chemicals.
- Use water-based rather then oil-based compounds when possible because water-based compounds are more easily decomposed (less biopersistent) than oil-based compounds.
- When landscaping, select native plants which have low requirements for water, fertilizers and pesticides.
- Test your soil before fertilizing. Over fertilization is a common but avoidable problem. The excess runs off your lawn or garden and fertilizes/contaminates nearby surface and groundwater supplies.

The Finger Lakes Institute's Lake Friendly Households program is a source of additional information on household waste management.

Table 1. National Drinking Water Standards: Some Examples.

Contaminant	Maximum Contaminant Level (MCL) in mg/L	Comments/Problems
Inorganics		
Arsenic	0.05	Highly toxic
Cadmium	0.01	Kidney
Lead	0.015*	Highly toxic
Mercury	0.002	Kidney, nervous system
Selenium	0.01	Nervous system
Asbestos	7 MFL	Benign tumors
Fluoride	4	Skeletal damage
Organic compounds		
Pesticides		
Endrin	0.0002	Nervous system, kidney
Lindane	0.004	Nervous system, kidney, liver
Methoxychlor	0.1	Nervous system, kidney, liver
Herbicides		
2,4D	0.07	Liver, kidney, nervous system
Silvex	0.05	Nervous system, liver, kidney
Volatile organic compounds		
Benzene	0.005	Cancer
Carbon tetrachloride	0.005	Possible cancer
Trichloroethylene	0.005	Possible cancer
Vinyl chloride	0.002	Cancer risk
Microbiological organisms		
Fecal coliform bacteria	1 cell/100 mL	Indicator-disease causing organisms

* There is no MCL for Lead. The concentration listed is instead the "action" level for lead related to treatment of water to reduce lead to a safe level.

MFL: Million fibers per liter with fiber length > 10 micrometers.

Source: U.S. Environmental Protection Agency.

RESOURCES

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