Primer for Municipal Wastewater Treatment Systems

The Need for Wastewater Treatment

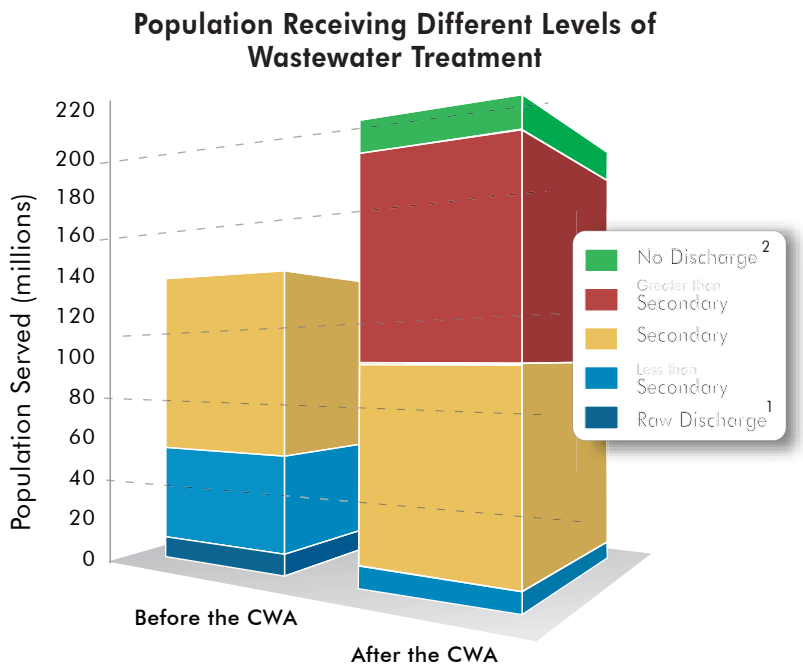
Wastewater treatment is needed so that we can use our rivers and streams for fishing, swimming and drinking water. For the first half of the 20th century, pollution in the Nation's urban waterways resulted in frequent occurrences of low dissolved oxygen, fish kills, algal blooms and bacterial contamination. Early efforts in water pollution control prevented human waste from reaching water supplies or reduced floating debris that obstructed shipping. Pollution problems and their control were primarily local, not national, concerns. Since then, population and industrial growth have increased demands on our natural resources, altering the situation dramatically. Progress in abating pollution has barely kept ahead of population growth, changes in industrial processes, technological developments, changes in land use, business innovations, and many other factors. Increases in both the quantity and variety of goods produced can greatly alter the amount and complexity of industrial wastes and challenge traditional treatment technology. The application of commercial fertilizers and pesticides, combined with sediment from growing development activities, continues to be a source of significant pollution as runoff washes off the land.

Water pollution issues now dominate public concerns about national water quality and maintaining healthy ecosystems. Although a large investment in water pollution control has helped reduce the problem, many miles of streams are still impacted by a variety of different pollutants. This, in turn, affects the ability of people to use the water for beneficial purposes. Past approaches used to control water pollution control must be modified to accommodate current and emerging issues

Effects of Wastewater on Water Quality

The basic function of the wastewater treatment plant is to speed up the natural processes by which water purifies itself. In earlier years, the natural treatment process in streams and lakes was adequate to perform basic wastewater treatment. As our population and industry grew to their present size, increased levels of treatment prior to discharging domestic wastewater became necessary.

(Data form U.S. Public Health Service multi wastewater inventories: 2000 USEPA Clean Watershed Needs Survey)



[1] Raw discharges were eliminated by 1996
[2] Data for the "no-discharge" category were unavailable for 1968

Collecting and Treating Wastewater

The most common form of pollution control in the United States consists of a system of sewers and wastewater treatment plants. The sewers collect municipal wastewater from homes, businesses, and industries and deliver it to facilities for treatment before it is discharged to water bodies or land, or reused.

Centralized Collection

During the early days of our nation's history, people living in both the cities and the countryside used cesspools and privies to dispose of domestic wastewater. Cities began to install wastewater collection systems in the late nineteenth century because of an increasing awareness of waterborne disease and the popularity of indoor plumbing and flush toilets. The use of sewage collection systems brought dramatic improvements to public health, further encouraging the growth of metropolitan areas. In the year 2000 approximately 208 million people in the U.S. were served by centralized collection systems.

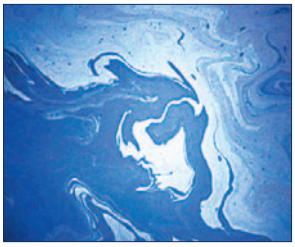
Some of the key challenges faced by wastewater treatment professionals today:

- Many of the wastewater treatment and collection facilities are now old and worn, and require further improvement, repair or replacement to maintain their useful life;
- The character and quantity of contaminants presenting problems today are far more complex than those that presented challenges in the past;
- Population growth is taxing many existing wastewater treatment systems and creating a need for new plants;
- Farm runoff and increasing urbanization provide additional sources of pollution not controlled by wastewater treatment; and
- One third of new development is served by decentralized systems (e.g., septic systems) as population migrates further from metropolitan areas.

Combined Sewer Systems

Many of the earliest sewer systems were combined sewers, designed to collect both sanitary wastewater and storm water runoff in a single system. These combined sewer systems were designed to provide storm drainage from streets and roofs to prevent flooding in cities. Later, lines were added to carry domestic wastewater away from homes and businesses. Early sanitarians thought that these combined systems provided adequate health protection. We now know that the overflows designed to release excess flow during rains also release pathogens and other pollutants.

Simplified Urban Water Cycle



Pollutants

Oxygen-Demanding Substances

Dissolved oxygen is a key element in water quality that is necessary to support aquatic life. A demand is placed on the natural supply of dissolved oxygen by many pollutants in wastewater. This is called biochemical oxygen demand, or BOD, and is used to measure how well a sewage treatment plant is working. If the effluent, the treated wastewater produced by a treatment plant, has a high content of organic pollutants or ammonia, it will demand more oxygen from the water and leave the water with less oxygen to support fish and other aquatic life.

Organic matter and ammonia are "oxygen-demanding" substances. Oxygen-demanding substances are contributed by domestic sewage and agricultural and industrial wastes of both plant and animal origin, such as those from food processing, paper mills, tanning, and other manufacturing processes. These substances are usually destroyed or converted to other compounds by bacteria if there is sufficient oxygen present in the water, but the dissolved oxygen needed to sustain fish life is used up in this break down process.

Pathogens

Disinfection of wastewater and chlorination of drinking water supplies has reduced the occurrence of waterborne diseases such as typhoid fever, cholera, and dysentery, which remain problems in underdeveloped countries while they have been virtually eliminated in the U.S.

Infectious micro-organisms, or pathogens, may be carried into surface and groundwater by sewage from cities and institutions, by certain kinds of industrial wastes, such as tanning and meat packing plants, and by the contamination of storm runoff with animal wastes from pets, livestock and wild animals, such as geese or deer. Humans may come in contact with these pathogens either by drinking contaminated water or through swimming, fishing, or other contact activities. Modern disinfection techniques have greatly reduced the danger of waterborne disease.

Nutrients

Carbon, nitrogen, and phosphorus are essential to living organisms and are the chief nutrients present in natural water. Large amounts of these nutrients are also present in sewage, certain industrial wastes, and drainage from fertilized land. Conventional secondary biological treatment processes do not remove the phosphorus and nitrogen to any substantial extent -- in fact, they may convert the organic forms of these substances into mineral form, making them more usable by plant life. When an excess of these nutrients overstimulates the growth of water plants, the result causes unsightly conditions, interferes with drinking water treatment processes, and causes unpleasant and disagreeable tastes and odors in drinking water. The release of large amounts of nutrients, primarily phosphorus but occasionally nitrogen, causes nutrient enrichment which results in excessive growth of algae. Uncontrolled algae growth blocks out sunlight and chokes aquatic plants and animals by depleting dissolved oxygen in the water at night. The release of nutrients in quantities that exceed the affected waterbody's ability to assimilate them results in a condition called eutrophication or cultural enrichment.

Inorganic and Synthetic Organic Chemicals

A vast array of chemicals are included in this category. Examples include detergents, household cleaning aids, heavy metals, pharmaceuticals, synthetic organic pesticides and herbicides, industrial chemicals, and the wastes from their manufacture. Many of these substances are toxic to fish and aquatic life and many are harmful to humans. Some are known to be highly poisonous at very low concentrations. Others can cause taste and odor problems, and many are not effectively removed by conventional wastewater treatment.

Thermal

Heat reduces the capacity of water to retain oxygen. In some areas, water used for cooling is discharged to streams at elevated temperatures from power plants and industries. Even discharges from wastewater treatment plants and storm water retention ponds affected by summer heat can be released at temperatures above that of the receiving water, and elevate the stream temperature. Unchecked discharges of waste heat can seriously alter the ecology of a lake, a stream, or estuary.

Workers install sewer line

Sanitary Sewer Systems

Sanitary sewer collection systems serve over half the people in the United States today. EPA estimates that there are approximately 500,000 miles of publicly-owned sanitary sewers with a similar expanse of privately-owned sewer systems. Sanitary sewers were designed and built to carry wastewater from domestic, industrial and commercial sources, but not to carry storm water. Nonetheless, some storm water enters sanitary sewers through cracks, particularly in older lines, and through roof and basement drains. Due to the much smaller volumes of wastewater that pass through sanitary sewer lines compared to combined sewers, sanitary sewer systems use smaller pipes and lower the cost of collecting wastewater.

Wastewater Treatment

In 1892, only 27 American cities provided wastewater treatment. Today, more than 16,000 publicly-owned wastewater treatment plants operate in the United States and its territories. The construction of wastewater treatment facilities blossomed in the 1920s and again after the passage of the CWA in 1972 with the availability of grant funding and new requirements calling for minimum levels of treatment. Adequate treatment of wastewater, along with the ability to provide a sufficient supply of clean water, has become a major concern for many communities.

Primary Treatment

The initial stage in the treatment of domestic wastewater is known as primary treatment. Coarse solids are removed from the wastewater in the primary stage of treatment. In some treatment plants, primary and secondary stages may be combined into one basic operation. At many wastewater treatment facilities, influent passes through preliminary treatment units before primary and secondary treatment begins.

Preliminary Treatment

As wastewater enters a treatment facility, it typically flows through a step called preliminary treatment. A screen removes large floating objects, such as rags, cans, bottles and sticks that may clog pumps, small pipes, and down stream processes. The screens vary from coarse to fine and are constructed with parallel steel or iron bars with openings of about half an inch, while others may be made from mesh screens with much smaller openings.

Screens are generally placed in a chamber or channel and inclined towards the flow of the wastewater. The inclined screen allows debris to be caught on the upstream surface of the screen, and allows access for manual or mechanical cleaning. Some plants use devices known as comminutors or barminutors which combine the functions of a screen and a grinder. These devices catch and then cut or shred the heavy solid and floating material. In the process, the pulverized matter remains in the wastewater flow to be removed later in a primary settling tank.

"the ability to provide a sufficient supply of clean water continues to be a major national concern"

Basic Wastewater Treatment Processes

Physical

Physical processes were some of the earliest methods to remove solids from wastewater, usually by passing wastewater through screens to remove debris and solids. In addition, solids that are heavier than water will settle out from wastewater by gravity. Particles with entrapped air float to the top of water and can also be removed. These physical processes are employed in many modern wastewater treatment facilities today.

Biological

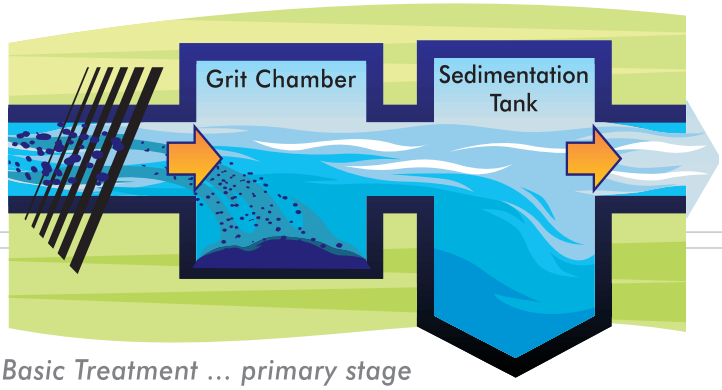
In nature, bacteria and other small organisms in water consume organic matter in sewage, turning it into new bacterial cells, carbon dioxide, and other by-products. The bacteria normally present in water must have oxygen to do their part in breaking down the sewage. In the 1920s, scientists observed that these natural processes could be contained and accelerated in systems to remove organic material from wastewater. With the addition of oxygen to wastewater, masses of microorganisms grew and rapidly metabolized organic pollutants. Any excess microbiological growth could be removed from the wastewater by physical processes.

Chemical

Chemicals can be used to create changes in pollutants that increase the removal of these new forms by physical processes. Simple chemicals such as alum, lime or iron salts can be added to wastewater to cause certain pollutants, such as phosphorus, to floc or bunch together into large, heavier masses which can be removed faster through physical processes. Over the past 30 years, the chemical industry has developed synthetic inert chemicals know as polymers to further improve the physical separation step in wastewater treatment. Polymers are often used at the later stages of treatment to improve the settling of excess microbiological growth or biosolids.

After the wastewater has been screened, it may flow into a grit chamber where sand, grit, cinders, and small stones settle to the bottom. Removing the grit and gravel that washes off streets or land during storms is very important, especially in cities with combined sewer systems. Large amounts of grit and sand entering a treatment plant can cause serious operating problems, such as excessive wear of pumps and other equipment, clogging of aeration devices, or taking up capacity in tanks that is needed for treatment. In some plants, another finer screen is placed after the grit chamber to remove any additional material that might damage equipment or interfere with later processes. The grit and screenings removed by these processes must be periodically collected and trucked to a landfill for disposal or are incinerated.

.



Basic Treatment ... primary stage

Primary Sedimentation

With the screening completed and the grit removed, wastewater still contains dissolved organic and inorganic constituents along with suspended solids. The suspended solids consist of minute particles of matter that can be removed from the wastewater with further treatment such as sedimentation or gravity settling, chemical coagulation, or filtration. Pollutants that are dissolved or are very fine and remain suspended in the wastewater are not removed effectively by gravity settling.

When the wastewater enters a sedimentation tank, it slows down and the suspended solids gradually sink to the bottom. This mass of solids is called primary sludge. Various methods have been devised to remove primary sludge from the tanks. Newer plants have some type of mechanical equipment to remove the settled solids from sedimentation tanks. Some plants remove solids continuously while others do so at intervals.

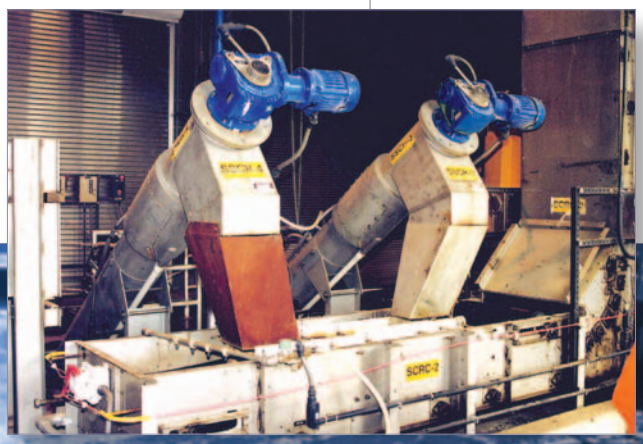
Secondary Treatment

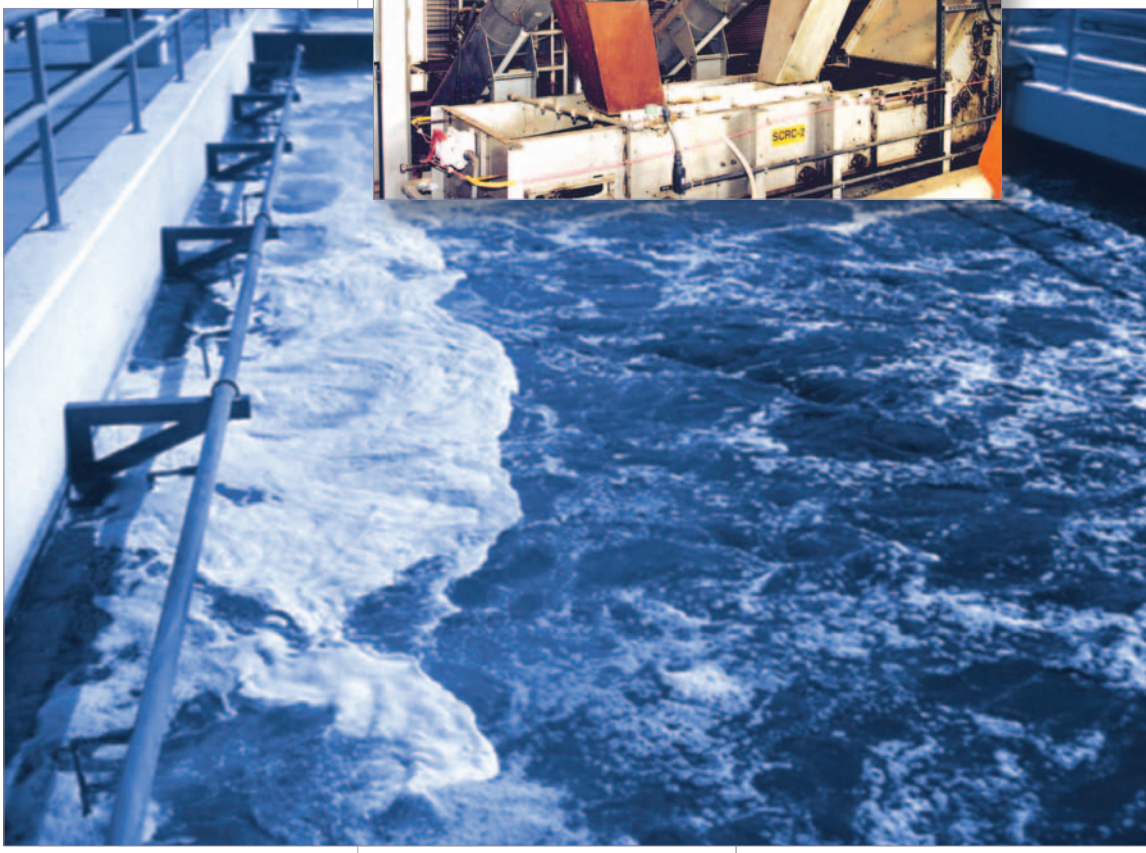
After the wastewater has been through Primary Treatment processes, it flows into the next stage of treatment called secondary. Secondary treatment processes can remove up to 90 percent of the organic matter in wastewater by using biological treatment processes. The two most common conventional methods used to achieve secondary treatment are attached growth processes and suspended growth processes..

Attached Growth Processes

In attached growth (or fixed film) processes, the microbial growth occurs on the surface of stone or plastic media. Wastewater passes over the media along with air to

Solids removed from automated bar screens





Aerated Grit Chamber

Sequencing Batch Reactor

provide oxygen. Attached growth process units include trickling filters, biotowers, and rotating biological contactors. Attached growth processes are effective at removing biodegradable organic material from the wastewater.

A trickling filter is simply a bed of media (typically rocks or plastic) through which the wastewater passes. The media ranges from three to six feet deep and allows large numbers of microorganisms to attach and grow. Older treatment facilities typically used stones, rocks, or slag as the media bed material. New facilities may use beds made of plastic balls, interlocking sheets of corrugated plastic, or other types of synthetic media. This type of bed material often provides more surface area and a better environment for promoting and controlling biological treatment than rock. Bacteria, algae, fungi and other microorganisms grow and multiply, forming a microbial growth or slime layer (biomass) on the media. In the treatment process, the bacteria use oxygen from the air and consume most of the organic matter in the wastewater as food. As the wastewater passes down through the media, oxygen-demanding substances are consumed by the biomass and the water leaving the media is much cleaner. However, portions of the biomass also slough off the media and must settle out in a secondary treatment tank.

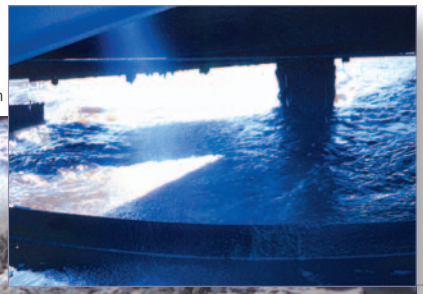
Trickling Filters

Suspended Growth Processes

Similar to the microbial processes in attached growth systems, suspended growth processes are designed to remove biodegradable organic material and organic nitrogen-containing material by converting ammonia nitrogen to nitrate unless additional treatment is provided. In suspended growth processes, the microbial growth is suspended in an aerated water mixture where the air is pumped in, or the water is agitated sufficiently to allow oxygen transfer. Suspended growth process units include variations of activated sludge, oxidation ditches and sequencing batch reactors.

The suspended growth process speeds up the work of aerobic bacteria and other microorganisms that break down the organic matter in the sewage by providing a rich aerobic environment where the microorganisms suspended in the wastewater can work more efficiently. In the aeration tank, wastewater is vigorously mixed with air and microorganisms acclimated to the wastewater in a suspension for several hours. This allows the bacteria

Brush Aerators in an Oxidation Ditch



Centerfeed well of a clarifier for removing excess biomass

and other microorganisms to break down the organic matter in the wastewater. The microorganisms grow in number and the excess biomass is removed by settling before the effluent is discharged or treated further. Now activated with millions of additional aerobic bacteria, some of the biomass can be used again by returning it to an aeration tank for mixing with incoming wastewater.

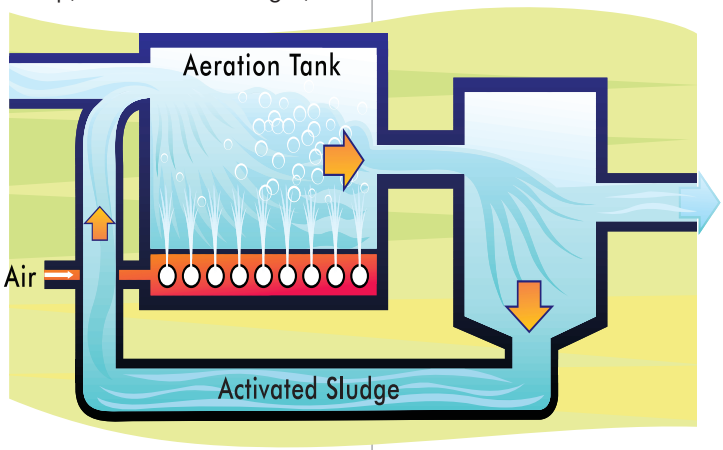
The activated sludge process, like most other techniques, has advantages and limitations. The units necessary for this treatment are relatively small, requiring less space than attached growth processes. In addition, when properly operated and maintained, the process is generally free of flies and odors. However, most activated sludge processes are more costly to operate than attached growth processes due to higher energy use to run the aeration system. The effectiveness of the activated sludge process can be impacted by elevated levels of toxic compounds in wastewater unless complex industrial chemicals are effectively controlled through an industrial pretreatment program.

An adequate supply of oxygen is necessary for the activated sludge process to be effective. The oxygen is generally supplied by mixing air with the sewage and biologically active solids in the aeration tanks by one or more of several different methods. Mechanical aeration can be accomplished by drawing the sewage up from the bottom of the tank and spraying it over the surface, thus allowing the sewage to absorb large amounts of oxygen from the atmosphere. Pressurized air can be forced out through small openings in pipes suspended in the wastewater. Combination of mechanical aeration and forced aeration can also be used. Also, relatively pure oxygen, produced by several different manufacturing processes, can be added to provide oxygen to the aeration tanks.

From the aeration tank, the treated wastewater flows to a sedimentation tank (secondary clarifier), where the excess biomass is removed. Some of the biomass is recycled to the head end of the aeration tank, while the remainder is "wasted" from the system. The waste biomass and settled solids are treated before disposal or reuse as biosolids.

Lagoons

A wastewater lagoon or treatment pond is a scientifically constructed pond, three to five feet deep, that allows sunlight,



Secondary Treatment Suspended Growth Process

Wastewater Lagoon

algae, bacteria, and oxygen to interact. Biological and physical treatment processes occur in the lagoon to improve water quality. The quality of water leaving the lagoon, when constructed and operated properly, is considered equivalent to the effluent from a conventional secondary treatment system. However, winters in cold climates have a significant impact on the effectiveness of lagoons, and winter storage is usually required.

Lagoons have several advantages when used correctly. They can be used for secondary treatment or as a supplement to other processes. While treatment ponds require substantial land area and are predominantly used by smaller communities, they account for more than one-fourth of the municipal wastewater treatment facilities in this country. Lagoons remove biodegradable organic material and some of the nitrogen from wastewater.

Land Treatment

Land treatment is the controlled application of wastewater to the soil where physical, chemical, and biological processes treat the wastewater as it passes across or through the soil. The principal types of land treatment are slow rate, overland flow, and rapid infiltration. In the arid western states, pretreated municipal wastewater has been used for many years to irrigate crops. In more recent years, land treatment has spread to all sections of the country. Land treatment of many types of industrial wastewater is also common.

Whatever method is used, land treatment can be a feasible economic alternative, where the land area needed is readily available, particularly when compared to costly advanced treatment plants. Extensive research has been conducted at land treatment sites to determine treatment performance and study the numerous treatment processes involved, as well as potential impacts on the environment, e.g. groundwater, surface water, and any crop that may be grown.

Slow Rate Infiltration

In the case of slow rate infiltration, the wastewater is applied to the land and moves through the soil where the natural filtering action of the soil along with microbial activity and plant uptake removes most contaminants. Part of the water evaporates or is used by plants. The remainder is either collected via drains or wells for surface discharge or allowed to percolate into the groundwater.

Slow rate infiltration is the most commonly used land treatment technique. The wastewater, which is sometimes disinfected before application, depending on the end use of the crop and the irrigation method, can be applied to the land by spraying, flooding, or ridge and furrow irrigation. The method selected depends on cost considerations, terrain, and the type of crops. Much of the water and most of the nutrients are used by the plants, while other pollutants are transferred to the soil by adsorption, where many are mineralized or broken down over time by microbial action.