Eco – Meet Study Packet
Drinking Water / Wastewater: The Urban Water Cycle
Phinizy Center for Water Sciences and ESG Operations: Education Department

Overview:

Drinking Water is a term used to describe the treated water that comes to our homes and businesses that we use daily for cooking, cleaning, bathing, and most importantly, drinking. This water is pulled from the natural environment and processed in order to be safe for use.

Wastewater refers to the drinking water after it has been used in our homes, businesses, and even factories. This water, as the name implies, contains ‘waste and contaminates’ and must be treated and cleaned before it can be returned back into the natural environment.

Water is a finite resource. This means that all the water that is on the planet is the same water that has ever been on the planet. We must understand water in the natural environment, its states of matter, and how it changes over time in order to be able to understand how we, as humans, fit into the broader process that is the natural water cycle.

ON WATER:

States of Water

Water is the only substance on Earth that exists naturally in three states---solid, liquid, and gas (See **Figure 1.1a** below). The state of water is determined by temperature.

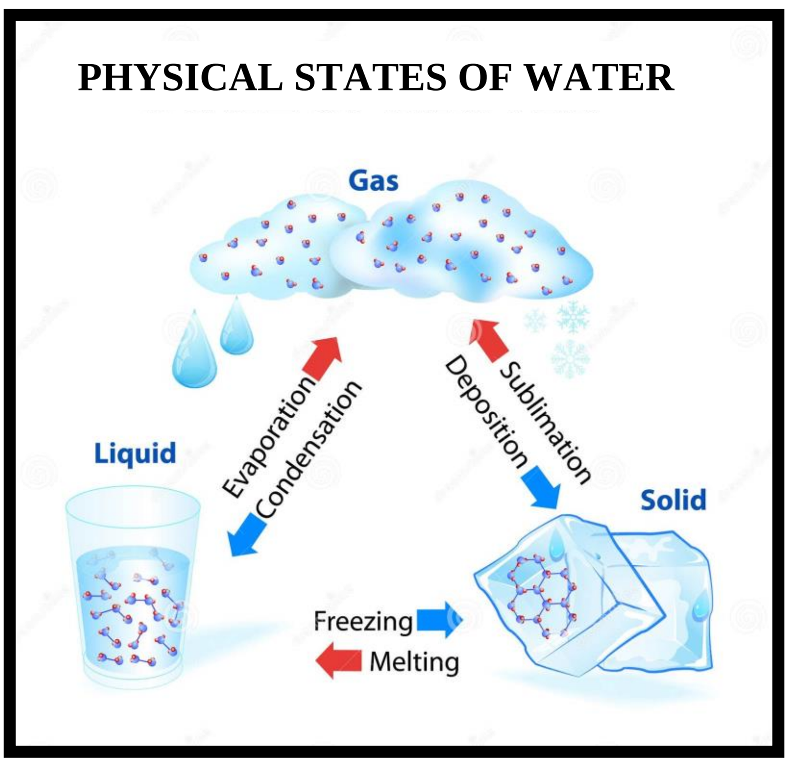


Figure 1.1a: The physical states of water are all determined by temperature. The red arrows indicate heat and the blue arrows indicate cooling.
Source: http://www.dreamstime.com

The Natural Water Cycle

The water cycle (also known as the **hydrologic cycle**) describes the continuous movement of water through land, air, and bodies of water. Water is constantly moving through the environment, changing locations and states of matter along the way (See **Figure 1.1b** below). Examples of this movement include:

- When water vapor in the atmosphere cools, it **condenses** into liquid water droplets to form clouds (**condensation, water changing from a gas to a liquid**). This water leaves the atmosphere as **precipitation** (rain, snow, sleet, or hail) and is deposited into lakes, rivers, oceans, and on land. Precipitation occurs when the clouds become full and heavy, and the water is pulled by gravity to the Earth.
- When heated, liquid water returns to the atmosphere in the form of water vapor through the process of **evaporation (water changing from a liquid to a gas)**.
- Ice may also change directly into water vapor. This process is called **sublimation (water changing from a solid to a gas)**. If the opposite occurs (water vapor turning to ice), it is called **deposition (water changing from a gas to a solid)**.
- Water flows downhill over land from higher to lower elevations as **surface runoff,** and enters into a body of water, such as a stream or river. This water then **flows** downstream into larger rivers and eventually to the oceans.
- Water can also infiltrate into the soil and can move laterally through spaces between soil particles as **subsurface runoff** (also known as **groundwater flow**). **Aquifers** are areas of bedrock underneath the earth that have pore spaces that allow the water to flow through.
- When liquid water in plants evaporates from the surface of leaves it is called **transpiration**. The term **evapotranspiration** refers to the sum of the evaporation of water *and* the transpiration of water from plants in the environment.

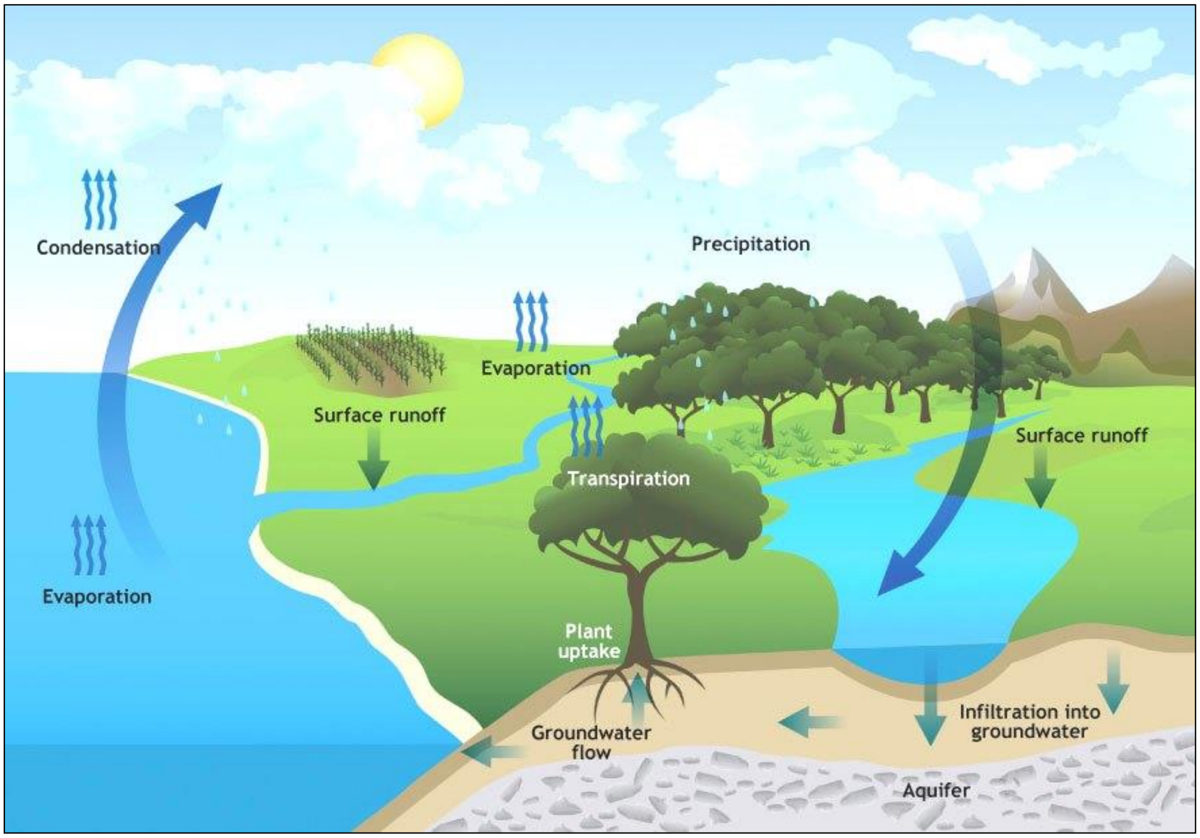


Figure 1.1b: The movement of water through the water cycle. Source: http://www.landscapeforlife.org

States of Water in the Natural Environment

- In the solid state, water exists as ice and snow and is common in glaciers and in polar and alpine regions.
- Water in the gas or vapor state can be felt on days with high humidity and seen in clouds, fog, steam from boiling water, or a vapor trail left by a passing airplane.
- Liquid water is found in bodies of surface water (e.g., oceans, rivers, lakes, streams and wetlands), groundwater, rain, and inside living organisms.

Humans and the Natural Water Cycle:

No species on earth has ever been better at manipulating the natural water cycle than humans. Since early civilization, humans have diverted water from our natural water bodies to use in agriculture, for transportation, for drinking water, and many other activities. Human activity has an impact on the quality of the water in the natural environment. Being mindful of the impact on the quality of the local water systems is essential in order for the water to remain as clean as possible for future use and for environmental health.

Urban Impacts to the Water Cycle

Areas where the human population is high, such as large towns and cities, are defined as **urban**. The landscape in these urban areas has been greatly altered for human activities. Changing the landscape to make way for homes, businesses, roadways, parking lots and even manicured lawns and ball fields can impact the quality and quantity of water in urban streams (or creeks and rivers that run through cities).

Most urban areas are run by a local government or **municipality.** Municipalities develop and maintain the **infrastructure** of the city. Infrastructure is a term used to describe the structure of the city which includes road systems, powerlines, phone and cable lines, sewer lines, drinking water lines, and storm drains.

Local governments also run **municipal facilities** which include community centers, public libraries, public parks and recreation areas, **drinking water facilities**, **wastewater treatment facilities**, city courthouses and correctional institutions. All municipal facilities are paid for by the local taxes that citizens within the community pay. Upgrading some of the infrastructure in a city as technology advances, such as changing the pipes used to transport water in the city from lead pipes to CPVC pipes, can be quite costly, potentially costing tax payers billions of dollars.

Impact from activities in these URBAN areas include:

- **Development**, which includes new home construction, shopping malls, municipal facilities, hospitals, businesses and road systems.
    - Removing vegetation from the landscape, by chopping down forests or clear-cutting areas, and adding cement and asphalt increases the amount of impervious surfaces in the landscape. **Impervious surfaces** (such as roads, driveways, parking lots, roofs, sidewalks and even compacted ball fields) are surfaces that do not allow water to pass through. Rainwater falling onto these surfaces cannot infiltrate the soil.
    - Impervious surfaces increase surface runoff, causing a greater volume of water to flow more quickly into rivers and streams. Also, less water infiltrating the soil means less water to aquifers or to recharge groundwater supply.

    - Increased surface runoff leads to more flooding of streams and rivers, as well as *erosion* and *heavy sediment loads* to the streams**. Excess sediment** in the water can increase cloudiness, clog the gills of aquatic animals, block sunlight from plants, and have other negative impacts on the habitat and ecosystem overall.
    - Parking lots and roads can accumulate contaminants from vehicles, including oil, gas, tire residue, weathered paint, and road salts. Surface runoff transports these contaminants to streams, decreasing the quality of the water.
- **Urban houses, businesses, and industries** take water from streams for irrigation, drinking water, and manufacturing. Water from these areas is typically discharged to a stream from both storm drains and wastewater treatment facilities. If the water taken and the water replaced back into the natural ecosystem surrounding these areas is not managed properly, the quality of water in these areas can diminish quickly.

Maintaining good habitat and water quality in urban streams is essential to sustaining a quality source of water for citizens. Building urban infrastructure with the health of streams in mind can prevent future costs to residents that could potentially come from stream habitat restoration and water quality maintenance projects.

Rural Impacts to the Water Cycle

Areas where the population is low (usually thought of as the countryside), which includes farmland and small towns, are referred to as **rural**. These areas tend to have long distances between homes and businesses. Landscape in these areas is generally altered for roads, farms, and house sites, but has far less infrastructure than urban areas.

Homes in rural areas tend to derive their drinking water from wells and treat their wastewater with **septic systems** (see the wastewater treatment section). Wells and septic systems are paid for by the individual home owner, and it is their responsibility to maintain these systems and keep them in working order.

Impact from activities in these RURAL areas include:

- **Agriculture**, which includes farmland for crops, pastures, and livestock feedlots
    - Loose soil from agricultural areas increases the amount of sediment in surface runoff, which flows into the stream.
    - Use of fertilizers, herbicides, pesticides, and fungicides adds excess nutrients and inorganic contaminants to surface runoff. Once this surface runoff reaches the stream it can harm the stream by causing algal blooms and depleting oxygen levels in the water.
    - Concentrated animal feeding operations and pastures can add harmful excess nutrients and fecal coliform bacteria to streams from animal excrement.
    - Irrigation for crops can remove large amounts of water from local streams or ground water. Depleting aquafers can cause major issues with ground water supply.
- **Homes sites** are generally on septic systems. If these systems are not properly maintained, they can overflow into groundwater and streams, causing increased nutrients and fecal coliform bacteria in the water.

ON DRINKING WATER:

General Background

Humans rely on water for survival---for cooking, cleaning, agriculture, personal hygiene, and, most importantly, for drinking. Early civilizations were established near water sources for this reason, and most large urban areas today are located near an adequate water source.

The concept of treating drinking water arose when people began to notice that those who lived near sources of clear, good-tasting water were rarely sick, compared to those who lived near and drank water that was **turbid** (cloudy or murky). Some examples of early drinking water treatment include:

- Greek and Sanskrit writings from as early as 4000 BC that recommended purifying water by filtering with charcoal, boiling, or exposing to sunlight (UV rays). These methods are still used today.
- Egyptians used Aluminum sulfate (alum) to cause particles to clump together and settle out of water as early as 1500 BC. Alum is still used today in municipal drinking water facilities.
- In 500 BC, the famous Greek physician Hippocrates invented the first domestic water filter (known as Hippocrates' sleeve) by pouring boiled rainwater through a cloth bag.

Early Drinking Water Distribution Systems

Ancient civilizations, in areas today known as Peru, Iran, India, Greece, and Egypt had advanced public water supply and drainage systems. Ancient Rome's public water system is famous for its numerous and large aqueducts.

- The **Roman Aqueducts** carried water by gravity to cities throughout the Roman Empire (See **Figure 1.5**). The first Roman aqueduct was constructed in 312 BC. Most were underground, but those that were above ground used arched bridges to transport water over irregular terrain. Water from aqueducts was stored in reservoirs and piped to bathhouses, public fountains, and private homes of wealthy and influential citizens.

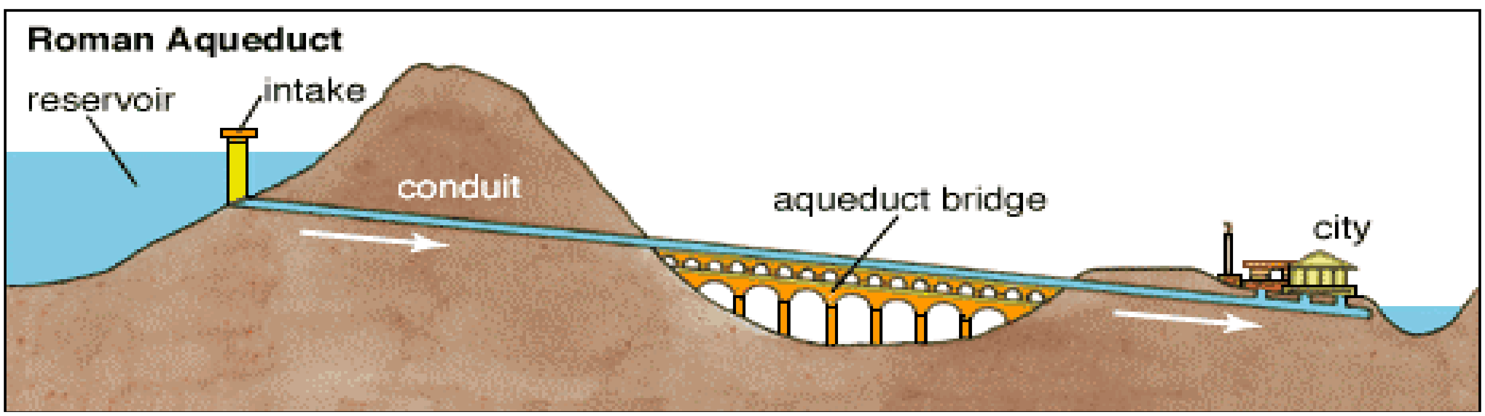


Figure 1.5: Early water systems in the Roman Empire worked by the force of gravity alone.
Source: Encyclopedia Britannica

- After the Roman Empire fell, many of the aqueducts fell into disrepair or were destroyed in war (476 – about 1400 AD). During the Dark Ages (~1300 – 1600 AD), much of the advanced water supply technology developed in Rome was lost. Drinking water supplies were frequently contaminated with wastewater and plagues spread throughout Europe for centuries.

- Very little progress in drinking water treatment or distribution was made until the early 1800s, when many European cities began filtering drinking water through sand. The **first public drinking water facility** was built in Scotland in 1804. Water was treated with sand and gravel filtration and delivered to homes in a horse-drawn cart. This pioneered the novel idea of providing all residents with access to clean drinking water.
- At about the same time (late 1700s - early 1800s), people in the United States collected their drinking water from wells, springs, or nearby streams. Many larger cities had small distribution systems to provide water for firefighting. These systems used hollowed logs for pipes and only served the city centers.
- The invention of **steam and electrical power** allowed water to be pumped long distances and to areas of higher elevation. The switch from wooden to cast iron pipes meant that systems could withstand the high water pressures necessary to deliver water to multiple homes. Powerful new excavation equipment made it possible to dig deep, long trenches for pipes and wells (before this, trenches were dug by hand!). This allowed the distribution of water on a much larger scale.
- This new technology allowed cities and larger towns throughout the US to build extensive drinking water systems during the late 1800s and early 1900s. In 1899, the Highland Avenue Water Treatment Facility was built to treat Augusta's municipal drinking water. In rural areas and smaller towns, people continued to use wells and springs for their drinking water.

Around the same time these new distribution systems were being built, cities also began to make advancements in the drinking water treatment process.

History of Drinking Water Treatment in the U.S.

Throughout history, people judged the quality of water by its appearance, smell, and taste. When scientists discovered that diseases like cholera and typhoid fever were caused by microorganisms in water, it proved that good taste and clarity do not always indicate safe drinking water.

- The incidence of waterborne diseases was dramatically reduced when cities began disinfecting drinking water with chlorine in the early 1900s. In 1914, the US Public Health Service set standards limiting the number of bacteria present in municipal drinking water.
- Initially, drinking water treatment focused on reducing pathogens (microorganisms that cause illness). In the 1960s, the focus shifted to include the removal of heavy metals, toxins, and man-made industrial chemicals, all of which were showing up in the water source.
- In 1969, a survey by the US Public Health Service revealed that only 60% of municipal water systems were meeting quality standards. This revelation combined with the increase in awareness of environmental issues encouraged Congress to pass the **Safe Drinking Water Act of 1974** (improved and amended in 1986 and 1996). This law limits the amounts of contaminants present in municipal drinking water and requires municipal facilities to provide an annual report of contaminants detected in drinking water to consumers. **Figure 1.6** below is a sample of a Richmond County, GA 2012 water report.

2012 WATER TESTING RESULTS

Substance	Year	MCL	MCLG	Groundwater Plants Amount Low-High	Highland Plant Amount Low-High	Hicks Plant Amount Low-High	Violation	Source
Fluoride (ppm)	2012	4	4	0.15-1.41	0.35-1.13	0.61-0.97	no	Erosion of natural deposits; water additive that promotes strong teeth; discharge from fertilizer and aluminum factories
Chlorine (ppm)	2012	4	4	1.10-1.497	1.07– 2.20	0.95-1.85	no	Water additives used to control microbes
Nitrates (ppm)	2012	10	10	0.57-1.7	N/D	N/D	no	Runoff from fertilizer; leaching from septic tanks; sewage; erosion of natural deposits
Total Organic Carbon (ppm)	2012	TT	N/A	N/D	1.0-1.3	1.0-1.5	no	Naturally present in the environment
Total Trihalomethanes (ppm)	2012	0.08		0.001-0.03	0.017-0.065	0.003-0.078	no	By-product of drinking water disinfection
Total Haloacetic Acids (ppm)	2012	0.06	N/A	0.002-0.02	0.013-0.035	0.002-0.05	no	By-product of drinking water disinfection
Turbidity (NTU)	2012	TT		N/D	0.061-0.181	0.043-0.143	no	Soil runoff
Total Coliform (per 100 mLs)	2012	< 5%	0	0	0	0	no	Commonly present in the environment; human and animal waste

Tap water samples were collected for lead and copper analysis from 50 homes throughout the service area.

Substance	Year	Action Level	MCLG	Amount detected (90th Percentile)	Homes Above Action Level	Violation	Source
Copper (ppb)	2010	1,300	1,300	160	0	No	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preserva-tives
Lead (ppb)	2010	15	0	2.5	1	No	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preserva-tives
Alpha Emitters (pCi/L)	2007	15	0	<2	<2	No	Erosion of natural deposits of certain radioactive materials
Radium (226 & 228) (pCi/L)	2007	5	0	<2	<2	No	Decay of natural and manmade deposits of certain radioactive materials

Figure 1.6: Sample from Richmond County 2012 report on water quality testing. These results are sent out to the residents of Richmond County along with their water utility bill. Source: Augusta Utilities

Surface and Groundwater

Today approximately 70% of US households receive drinking water from surface water sources (such as lakes, reservoirs, and rivers), while 30% receive drinking water from groundwater sources (such as springs and public or private wells).

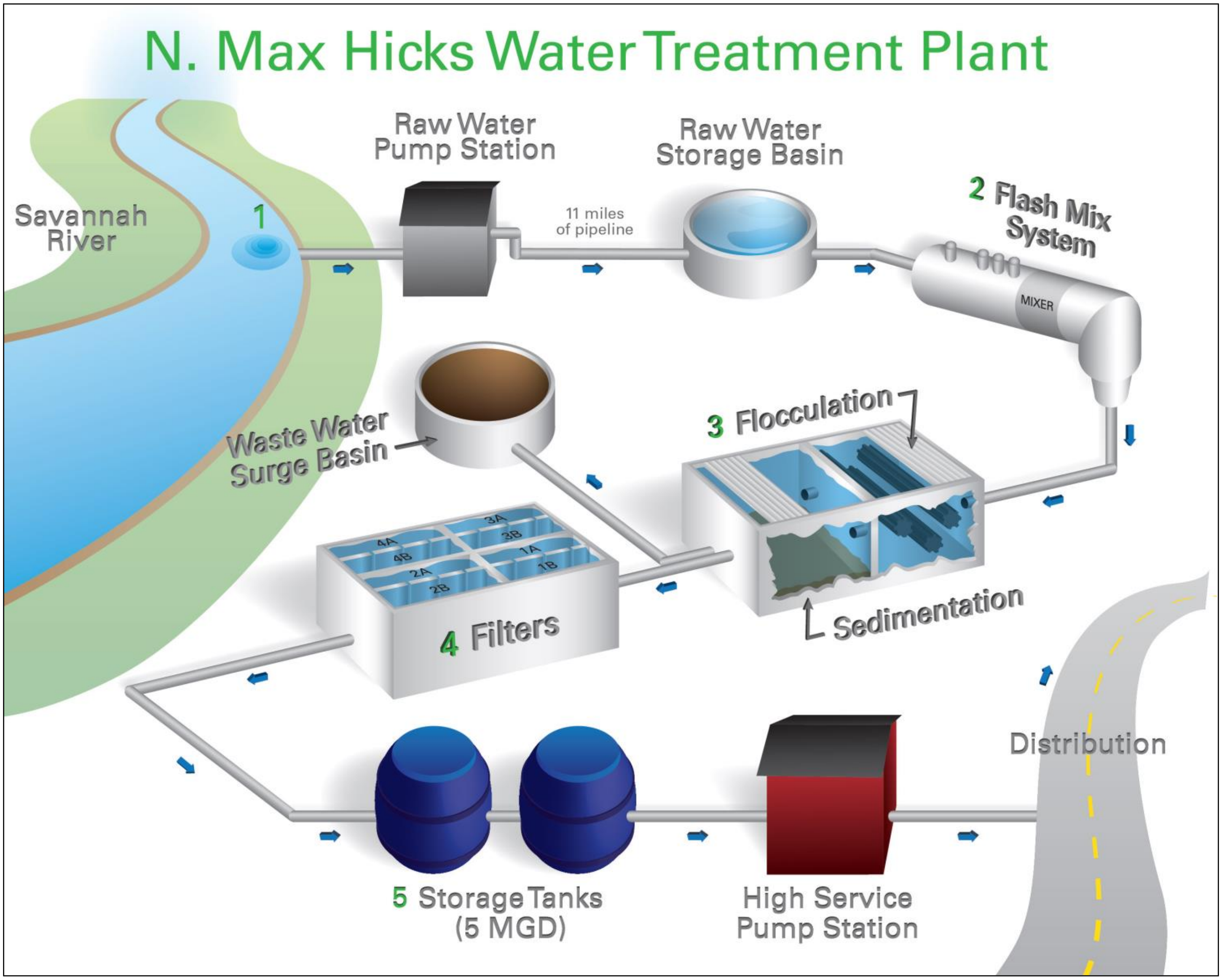
- In most urban areas, the majority of drinking water is drawn from surface water (which requires significant treatment). Ground water is used to a lesser extent.
- In rural areas, connecting individual buildings to a city water system is very expensive and inefficient. As a result, most rural residents rely on groundwater from private wells, usually located on their own property. Groundwater is typically free of contaminants. However, there is the potential of contamination from subsurface runoff, including sources such as fertilized lawns, oil spills, and leaking septic systems. Homeowners are responsible for periodic testing of their well water to ensure it is safe to drink.

Drinking Water Treatment Process

The main function at a drinking water treatment facility is to produce clear, **potable** (safe to drink) water, free of pathogens and contaminants. The clarity of the water is an important measure. Raw (untreated) water is often **turbid** (cloudy or murky) and the goal at the drinking water facility is to minimize **turbidity**– in other words, make the water crystal clear, and also remove pathogens and other contaminants.

The following is a typical process used to treat drinking water by municipal drinking water facilities around the United States. **Figure 1.7** on page 9 is specific to the N. Max Hicks Drinking Water Treatment Plant in Augusta, Georgia.

- **Raw Water Pumping Station:** At the raw water pumping station, water is pumped from the water source (which is usually a river, lake, reservoir or ground water source) and sent to the treatment plant. There are usually screens at the pumping station that prevent sticks, leaves, and other large items from entering the system.
- **Raw Water Reservoir** Many municipal treatment plants store water in a reservoir before treatment. Reservoirs can be useful for many reasons and are the first step in treatment.
    - If the raw water is turbid, allowing it to sit in a reservoir for several days helps sediment, such as soil or dirt particles, settle out and fall to the bottom of the reservoir. Removing the sediment and settable solids reduces the raw water turbidity.
    - Reservoirs typically store 3 to 5 days' worth of a community's water supply. If something happens to the water supply, such as an oil spill or other contamination, the raw water pumping station can be turned off until the contamination has either been washed downstream or been removed and is no longer a threat. The water in the reservoir can act as a water supply until the raw water pumping station is back online.
    - Storage basins or reservoirs are located uphill from treatment plants so water can flow by gravity through the plant, eliminating the need for costly pumps.
- **Flash Mix System** Once water leaves the reservoir it passes through a flash mix system where different chemicals are added to aid in treatment. Some of the chemicals added in the flash mix include chlorine for pre-disinfection and Alum (Aluminum Sulfate) to aid with flocculation.
- **Flocculation & Sedimentation** After passing through the flash mix system, the water enters the flocculation & sedimentation basin. Retention time is extremely important in this basin. The Alum (and polymer, which aids the Alum) causes small particles in the water to clump and stick together. As the clumps get bigger and heavier, they settle to the bottom of the basin. The cleaner, less turbid water, can then be taken from the top and sent to the next step in the treatment process. The particles that settle to the bottom, called sludge, are removed and sent off for proper treatment, usually to a wastewater treatment plant.
- **Filtration Basin** From the sedimentation basin, the water continues to the filtration basin where it passes through a filter made of layers of anthracite (a form of carbon), gravel and sand. The water at this point is crystal clear. The filters must be flushed out and cleaned every few hours to remain effective.
- **Final Disinfection** After passing through the filters, chlorine, (usually in the liquid form of sodium hypochlorite (a common household bleach), is added for disinfection. The water then enters a storage tank before being distributed out to the community.
- **Other Additives** Other chemicals are sometimes added to the treated drinking water supply because they aid in the health of the community or the infrastructure.
    - **Lime** is often added in the treatment process in order to help with the 'hardness' of the water and control pH (the acidity of the water).
    - **Fluoride** is added to the water to help prevent tooth decay in small children.
    - **Phosphate** is added to coat and protect the pipes from corrosion.
    - **Potassium Permanganate** is used for keeping the taste of the water as neutral as possible.



1. RAW WATER PUMPED:
Raw water is drawn from the Savannah River and stored. A screen on the pump prevents sticks, leaves, and other large items from entering.

2. FLASH MIX SYSTEM:
Raw water is sent to a mixing system where chlorine is added to pre-disinfect the water.

3. FLOCCULATION & SEDIMENTATION:
Aluminum sulfate (alum) and polymer are added to the mixture, causing small particles to clump together (**flocculation**) and making them heavy enough to settle to the bottom as the water slowly moves from one end of the basin to the other (**sedimentation**). Removing these particles helps reduce turbidity.

4. FILTERS:
The water is filtered through layers of anthracite (a form of carbon), gravel, and sand. Clear water emerges.
Small amounts of chemicals are added.

- **Chlorine:** added to disinfect and maintain water quality in distribution system
- **Lime:** used to adjust the final pH and alkalinity
- **Fluoride:** added to prevent tooth decay
- **Phosphate:** used to protect pipes from corrosion

5. STORAGE TANKS:
Clean water is pumped to sanitized storage tanks and distributed to homes, schools, and businesses throughout Augusta.

Figure 1.7: A typical drinking water treatment process. Source: Augusta Utilities

Desalination
Over 95% of the water on Earth is salt water. Desalination is the process of converting salt water to fresh, potable water. It is achieved by heating ocean water to convert it to water vapor (**evaporation**), which leaves the salt behind, then cooling the vapor to form liquid water (**condensation**).

- This process has been used to provide water for both drinking and water used for industry.
- Desalination requires a large amount of energy, making the process extremely expensive. As a result, it has been generally limited to affluent coastal regions with small freshwater sources, such as Australia, Great Britain, northern Africa, and the Middle East. Desalination is also used in parts of Florida and California.
- Desalination produces brine (a very concentrated salt solution) as a waste product. The brine must be diluted (usually with treated wastewater) before it can be discharged into either deep saline aquifers or the ocean, or sprayed onto open areas such as golf courses.
- Both the expense and the environmental impact have made desalination an unfavorable solution to drinking water.

ON WASTEWATER:

General Description
Wastewater is any water that has passed through the pipes for use. It usually contains waste products from being used by people in homes or industrial processes, but also includes treated water that just passed through the system (like turning on a faucet and letting it run until the water turns cold or hot). Wastewater includes:

- **Domestic wastewater** comes from homes, schools, and businesses and includes water from toilets, sinks, water fountains, dishwashers, washing machines, and shower drains. Domestic wastewater contains dissolved materials, such as soap, toothpaste, oils, nutrients (which come from human waste and food products), and small amounts of solid organic waste.
- **Industrial wastewater** comes from factories and processing facilities and may contain heavy metals, toxic materials, and excess nutrients.

The **Clean Water Act** requires that nutrients and other materials be removed before wastewater can be discharged into natural bodies of water such as lakes and rivers. Treatment of wastewater prevents the spread of waterborne diseases, preserves the quality of drinking water sources and also helps maintain habitat quality for aquatic organisms in our waterways.

History of Wastewater Treatment and Disposal
Although cities were supplying treated drinking water for its citizens by the late 1800s, indoor plumbing (pipes leading into the house to deliver clean drinking water) did not become commonplace throughout the entire US until about the 1930s. Before this time modern bathrooms did not exist; people instead used outhouses located behind homes. The problems that occurred with this form of waste disposal led to many necessary changes in the way we dispose of wastewater.

- Outhouses were simple lavatories that consisted of a seat located above a hole in the floor. **Cesspits** or **privy vaults** were pits dug beneath outhouses to capture wastes which would eventually decompose and percolate through the soil. Cesspits with heavy use needed regular maintenance and emptying. As towns grew larger and the number of cesspits increased, overflows became more common. Overflowing cesspits became a contamination threat to drinking water sources such as rivers, reservoirs and groundwater.

- A deadly cholera outbreak occurred in the London district of Soho in the fall of 1854. The neighborhood had experienced a large growth in population and cesspit overflows were common. Many families could not afford the cost of having cesspits emptied. An investigation revealed the source of the outbreak to be a public well that had been contaminated by a nearby leaking cesspit. Ironically, this well was popular among residents for its clear, clean-tasting water. This caused one of the deadliest cholera outbreaks in England's history, killing 611 people in one month.
- The discovery of the cholera bacteria in wastewater led to the realization that wastewater must be disposed of away from drinking water supplies to avoid contamination and disease.
- As indoor plumbing became the standard, urban infrastructure was built to connect homes to public sewer systems. In other words, a maze of pipes was built under the cities to carry clean drinking water to homes and businesses and another maze of pipes was built to carry the wastewater away.
    - In areas with large amounts of suitable land, the sewer systems sent the wastewater to be used for irrigating farms (these were known as sewage farms), providing crops with both water and nutrients.
    - In other locations, wastewater was dumped directly into storm sewers (designed to handle storm runoff only), which lead to nearby water bodies. **Dilution** into large bodies of water was the method of wastewater disposal in most cities for decades. Dilution however, did nothing to eliminate pathogens.
    - With increasing population density, raw sewage disposal into rivers began to negatively impact water quality. This caused some of our lakes, rivers and beaches to be closed to fishing and swimming.
- Until the 20^{th} century, there were no laws in the US that mandated wastewater treatment and disposal. While many cities and towns began treating wastewater to protect drinking water sources and fisheries before the Clean Water Act (see page 12) made it mandatory, many others chose not to devote the time, tax money, and labor needed to build a wastewater treatment facility.
- In 1899, Congress passed the **Rivers and Harbors Appropriations Act**, which is considered the first environmental law enacted in the US. A provision (or piece) of the law known as the **Refuse Act** made it illegal to dispose refuse (trash or waste) into **navigable waters** (waters that could transport a boat) or tributaries that lead to navigable waters without a permit. The purpose of this law was not to prevent water pollution, but rather, to control dumping of materials that could impede boat traffic.
- By the early 1920s, many large cities still had no wastewater treatment at all, such as Boston, Cincinnati, St. Louis, Los Angeles, and Detroit. Even in cities that had municipal treatment facilities, a large portion of the population (particularly those outside of city centers) was not connected to the sewer system.
- After World War II, industrial and urban growth expanded dramatically. This occurring with very little sewer system infrastructure resulted in extensive pollution of lakes, rivers, and streams throughout the country. In 1945, the US Surgeon General warned that over half of the US population relied on drinking water supplies of questionable quality. For several years, legislators made numerous attempts at passing a law to protect water supplies (creating over 100 bills!), but were unsuccessful. Many Congressmen thought that each state should control its own waterways and did not like the idea of federal regulation. Others were worried that the towns in

their districts would have to raise taxes to pay for construction of expensive wastewater treatment facilities.

- As our country's population continued to grow, fewer and fewer residents were connected to municipal sewer systems. The problem of poor water quality in our rivers became so severe that Congress was compelled to act. Congress was finally able to pass the **Federal Water Pollution Control Act of 1948**, which provided funds to states for water quality surveys and construction of wastewater treatment facilities, BUT did not actually prevent or limit pollution. In fact, water pollution steadily increased and the quality of the nation's waterways continued to degrade.
- The Federal Water Pollution Control Act was amended several times in the first 20 years after its passage. One major change was the extension of protection to **intrastate waters** (bodies of water located entirely in one state) in addition to **interstate waters** (located in more than one state, such as the Savannah River – which flows through North Carolina, South Carolina, and Georgia).
- By 1960, only 50% of the US population had access to some form of wastewater treatment. Augusta, GA built the JB Messerly Water Pollution Control Plant in 1968 (Augusta's first and current treatment facility).
- Water quality in streams and rivers throughout the US would continue to be impacted by untreated sewage until the passage of the **Clean Water Act in 1972**, which made it against the law to dump untreated wastewater into streams. Dilution was no longer accepted as the solution. The Clean Water Act set limits on the amount of nutrient loads, bacteria, and solids that could be discharged into our waterways. Every city and town in the U.S. was and still is required to follow these standards. Heavy fines are placed on any discharge out of regulation.

Major Components of the Clean Water Act

- Establishes water quality standards for all navigable waters and water bodies leading or adjacent to navigable waters.
- Requires all municipal and industrial wastewater to be treated before disposal.
- Grants money to state governments to build and improve wastewater treatment facilities.
- Requires regular monitoring of water bodies to determine if water quality standards are being met.

Historic Wastewater Infrastructure

Early sewer systems were built solely to transport storm runoff from city streets to the nearest body of water. As urban populations grew larger and denser, overflows from household cesspits became more common. This often led to groundwater contamination and the spread of waterborne diseases.

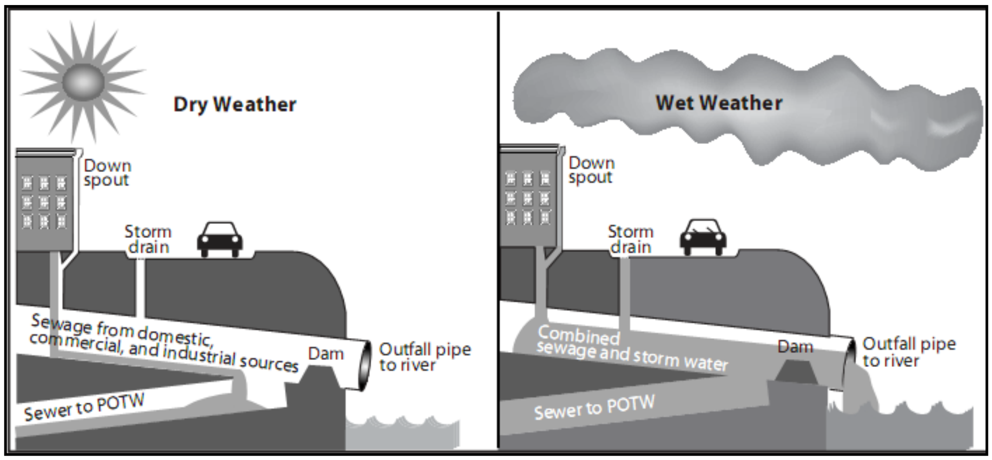
- To fix this problem, towns began constructing pipes to carry wastewater from homes to existing storm sewers. These became the first combined sewer systems. In **combined sewer systems (CSS)**, wastewater and storm runoff are collected and transported in a single system of pipes. CSS pipes must be large enough to handle both sewage and the large amount of runoff generated in a rainstorm (See **Figure 1.8** on pg. 13).
- After a series of cholera and yellow fever outbreaks in Memphis in the 1870s, city officials attempted to improve sanitary conditions with the construction of one of the nation's first **separate sewer system (SSS)**, designed to collect and transport wastewater using two separate systems of pipes: **sanitary sewers** for sewage and **storm sewers** (now called storm drains) for runoff (See **Figure 1.8**). After cases of yellow fever and cholera decreased, the separate sewer system was heralded as a success and a viable alternative to combined sewer systems.

- When deciding which type of sewer system to build, city officials had to consider many factors, such as annual rainfall, population size and density, topography, and available funds for construction. At first, sanitary engineers thought that both types of sewer systems provided equivalent protection of drinking water sources. However, when cities began to treat wastewater, they recognized a major difference: with combined sewer systems, both runoff and wastewater are carried to the treatment facility. This means a much larger volume of water must be treated. This not only made treatment in combined systems more expensive, but there was a large variation in flow between wet and dry weather, making treatment more difficult.

Combined Sewer System

These systems allowed wastewater to overflow into natural waterways during heavy rain events.

POTW = publicly-owned treatment works (wastewater treatment facility)



Separate Sewer System

Newer systems do not allow wastewater to enter natural waterways in the event of heavy rainfall.

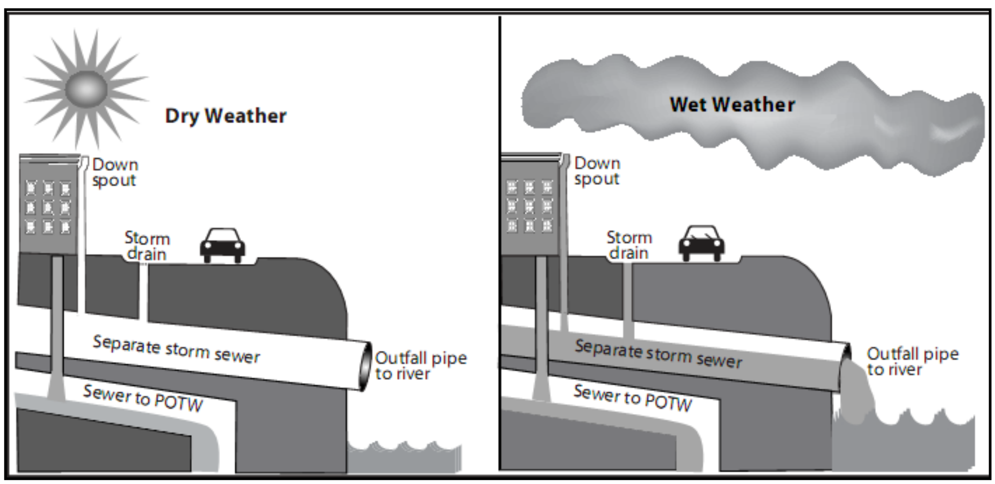


Figure 1.8: A comparison of Combined Sewer Systems (CSS) and newer Separate Sewer Systems (SSS).
Source: EPA Report to Congress on Impacts and Controls of CSOs and SSOs, 2004.

- In addition, a large rain event can cause a **combined sewer overflow (CSO)**, spilling sewage directly into a water body. Because of these issues, the construction of new combined sewer systems has been prohibited in the US since the 1950s. Over 700 cities and towns (mostly in the northeast) still use these systems due to the expense of replacing the old infrastructure. In most cases, these are in older cities where constructing a new sewer system would require excavating underneath existing structures. Upgrading and replacing infrastructure can cost into the billions of dollars.

ON WASTEWATER TREATMENT:

Early Wastewater Treatment Methods

From the late 1800s to the early 20th century, municipalities in the US experimented with several methods of wastewater treatment and disposal. Many of the earliest methods only provided minimal treatment; disinfection was rarely used. These include:

- **Mechanical treatment:** The earliest forms of wastewater treatment removed only trash and large debris from the water.
    - **Bar screens** and **cage racks**: Water passes through metal screens and racks, removing large items such as rags and plastic bags. The trash is then removed from the screens and sent to a landfill.
    - **Grit chambers:** The wastewater enters a large cylindrical tank where the flow of water is slowed down. As the water circles around the tank, a vortex is created and allows grit (sand and gravel) to settle to the bottom of the tank. This system was first used in the 1880s to protect pumps and other mechanical equipment.
    - Collectively the **bar screens** and **grit chambers** are the first steps still used in most wastewater **preliminary treatment**.

- **Biological treatment:** Involves the use of living organisms (typically bacteria and protozoa) to treat wastewater by breaking down the nutrient load. Early attempts at biological treatment include the following:
    - **Intermittent filtration**: Raw sewage was applied to a bed of sand a few feet in depth. As the wastewater passed through the sand, bacteria attached to sand particles processed the waste. The sewage had to be applied intermittently (a little at a time, with brief pauses between applications) to allow air to enter the spaces between the sand particles as the bacteria needed oxygen to break down the waste. Because of the high cost of operation and large amount of space required, this method was only used in a few small towns.
    - **Contact beds**: Similar to intermittent filtration, except that instead of sand, tanks were filled with gravel or coke (a coarse, solid material made from coal). Contact beds were allowed to remain full with wastewater for several hours (to give the bacteria time to digest the sewage), then remained empty for several hours while the spaces between the gravel filled with oxygen.
    - **Trickling filters**: Sewage was sprayed continuously onto a bed of gravel several feet deep on top of a concrete floor with a system of underlying drains. As the sprayed sewage traveled through the air and then through the gravel, it absorbed oxygen, which was used by bacteria living on the gravel to process the waste. Trickling filters were the most common type of treatment in the US through the 1920s.
    - **Septic tanks**: The earliest form of septic tanks was a step up from cesspits. Wastewater collected in the tank, where bacteria digested the solids that settled to the bottom, leaving liquid at the top. The treated sewage had a foul odor, and oil and grease often caused a floating mass of scum at the surface.
    - **Imhoff tanks**: Lessons learned from the use of early septic tanks led to the development of the Imhoff tank. This was a two-story tank in which sewage settled in the upper chamber and was digested in the lower chamber. This was an improvement on the septic tank, because the solids were digested to a greater degree and the treated sewage odor was much less offensive.

Current Wastewater Treatment Processes
As the population continued to grow in the US in the mid-1900s, it became apparent that advanced wastewater treatment was needed to improve the water quality in our rivers. The passage of The Clean Water Act in 1972 forced municipalities (including smaller cities and towns) to construct wastewater treatment facilities.

Most wastewater treatment facilities in the US today include preliminary treatment, primary treatment, secondary treatment and disinfection. Some cities with high volume of discharge have also added tertiary treatment. Both mechanical and biological treatment used in the early wastewater treatment are still used to some degree.

- **Preliminary treatment:** A mechanical treatment used to **get trash and other large debris out** of the system. Much of the trash removed should have never been in the wastewater to begin with, such as feminine hygiene products, rags, cigarette butts, condoms, plastic bags, toys, food wrappers and other plastics.
    - **Bar screens:** Large debris and trash collects on the bars and is removed by a mechanical rake, then taken to the landfill.
    - **Grit chamber:** A pump creates a vortex, slowing the flow of the water and allowing grit (mostly sand and gravel) to settle to the bottom of the chamber. It is important to remove grit because it can damage expensive equipment in the facility.
    - **Lift station**: Water is pumped up to a higher elevation. This allows the water to flow by gravity through the rest of the facility. Pumps are costly and constantly require maintenance. Having a lift station and using gravity can eliminate the need for pumps throughout the entire process.
- **Primary treatment:** This process is a mechanical treatment where **suspended solids are removed.** The movement of wastewater is slowed down in this process to allow for settling. Some biological treatment takes place in the tanks but most biological treatment occurs in the secondary treatment.
    - **Sedimentation tank** (also called a **primary clarifier**): This method works on retention time. The wastewater moves very slowly from one end of the tank to the other. As it moves, **sludge** (solid waste – yes organic human waste) falls to the bottom and **scum** (fats, oils, and grease---collectively known as **FOG**) floats to the top.
    - Slow-moving mechanical arms skim the scum off the surface. This scum, or **FOG**, has become an increasing problem in our sewer systems. Once the FOG is removed from the wastewater, it is disinfected and sent to the landfill. This is a very costly process which could be improved by educating our citizens on what not to dump down the drain.
    - **FOG (fats, oils, and grease)** includes used cooking oil, soap residue, salad dressing, gravy, mayonnaise, fat from meats and dairy, and other oily byproducts of cooking and food processing. Many sewer lines are located parallel to streams to take advantage of gravity to move sewage, as streams flow downhill. When sewer pipes break or sewage spills out of manholes due to FOG build-up, potentially thousands of gallons of wastewater could spill into the stream. Repairing damaged sewer systems costs taxpayers millions of dollars.
    - Mechanical arms scrap the sludge from the bottom of the tank. In some plants the sludge is sent to an **anaerobic digester** for processing. Bacteria, like the ones found in the gut or warm blooded animals, digest and reduce the sludge. After the sludge is reduced, it can

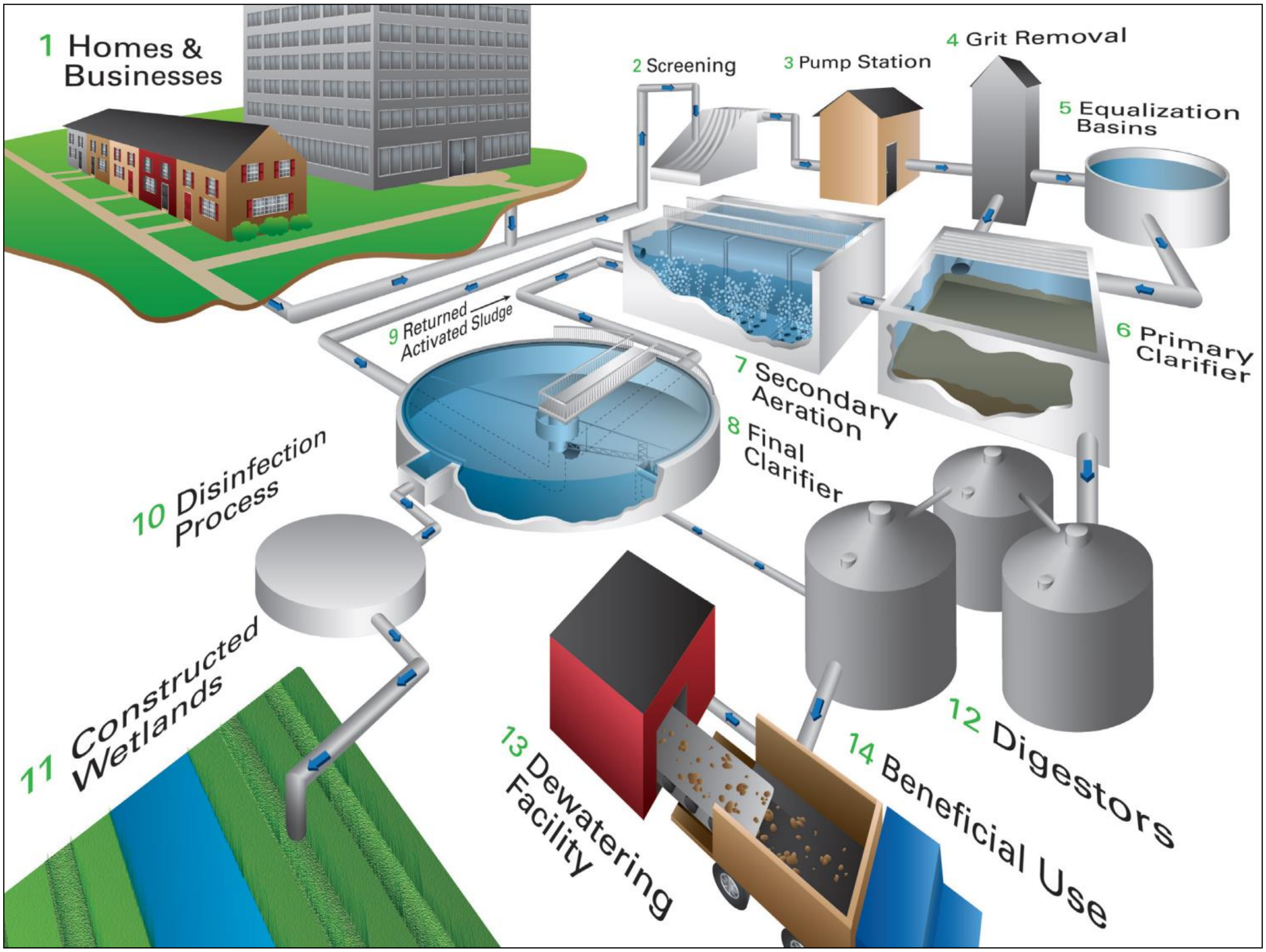
be sent to a landfill, sprayed on a sludge field, or sent off for land application. It is very rich in nutrient load so it can make a good fertilizer if treated properly.

- **Secondary treatment:** Once the scum and sludge are removed from the wastewater, the water continues on to a **biological treatment.**
  - **Activated sludge** is currently the world's most widely used wastewater treatment method. The activated sludge process involves using specific types of bacteria to break down the ammonia in wastewater (ammonia is a product of urea, a major component of urine) and convert it to nitrogen gas.
  - **Aeration basin**: Activated sludge is added to the wastewater in a large basin. **Activated sludge** is a liquid mixture of aerobic microorganisms (bacteria and protozoa that use oxygen for respiration) which feed on wastes and break down the high concentrations of nutrients. In the basin, varying amounts of oxygen are added to help the microorganisms function efficiently.
  - In Augusta, GA an advanced aeration basin was added in 2008. This process divides the aeration basin into chambers, each with different amounts of oxygen, to enhance treatment. One of the chambers is anaerobic (without oxygen) which adds an effective layer of treatment.
  - S**econdary clarifier**: After the wastewater exits the aeration basin, it is held in a large, circular basin, the secondary clarifier, allowing the microorganisms (activated sludge) to settle to the bottom and leaving clear water on top. A slow-moving arm scrapes the settled microorganisms off the bottom. Some of the microorganisms are sent back to the aeration basin for use in treatment (called **returned activated sludge**) and some are removed and sent to the digesters with the sludge.
- **Disinfection**: In the early 1900s, municipalities in which treated sewage was discharged close to drinking water supplies began disinfecting their wastewater with chlorine as the final treatment step before disposal. Disinfection insured that pathogens were killed before entering the streams. Disinfection was also used in areas like Providence, RI, where treated wastewater was discharged into tidal waters used for oyster culture. Major methods of wastewater disinfection include:
  - **Chlorination**: Chlorine gas or liquid sodium hypochlorite (a common household bleach) is mixed with wastewater for a specific **contact time**—the length of time the chemical must be in contact with the water in order to kill all pathogens. Although chlorine gas is cheaper than bleach, it is extremely toxic and explosive. After 9/11, most U.S. facilities switched to the safer liquid sodium hypochlorite. Chlorination is by far the mostly widely used method of wastewater disinfection around the world. After **dechlorination** (removing the chlorine), the treated water leaves the wastewater treatment facility and is safe to discharge back into the river as swimmable water
  - **Ultraviolet (UV) radiation**: Mercury lamps generate UV rays that kill pathogens in wastewater by damaging their DNA so that they can't reproduce. UV radiation has a much shorter contact time (~30 seconds) than chlorination and leaves no chemical residue that can harm aquatic organisms.
  - **Ozonation**: Ozone (O_3) is an unstable gas generated when oxygen (O_2) passes through an area with an electrical charge. It is highly reactive and oxidizes most organic material on contact, thus killing pathogens. Because of its instability, O_3 must be generated on site, which makes this method expensive due to the high cost of O_3 generation equipment.

- **Tertiary treatment**: Many industrial and municipal treatment facilities have added a tertiary (third) step to their treatment processes. This third step is often necessary to ensure that streams receiving treated waters meet water quality standards. Tertiary treatment methods include:
  - **Filtration**: Treated wastewater can be filtered with sand (which removes suspended particles) or with activated carbon (which removes toxins).
  - **Lagooning**: This involves storing treated wastewater in a large, man-made pond, often with native wetland plants. The stems and leaves of the plants are colonized with specific bacteria, fungi, and protozoa that decompose organic material and remove excess nutrients such as nitrogen and phosphorus. Many industries use lagoons to treat their wastewater, instead of sending it to the municipal treatment facility.
  - **Chemical precipitation**: This method is used to remove phosphorus, usually from industrial wastewater with high concentrations. Chemicals (such as alum, lime, or iron chloride) are added to wastewater and chemically react with the phosphorus, forming a sludge that settles to the bottom. The phosphorus-rich sludge can then be used as fertilizer.
  - **Constructed wetlands**: Constructed (manmade) wetlands use a process similar to that of lagoons; Bacteria and other microorganisms attached to plants decompose organic waste as the water flows slowly through the wetland. This method is also used by industries to treat wastewater.
  - In 1996, Augusta, GA added tertiary treatment as a solution for a wastewater treatment violation. The process includes the use of constructed wetlands for tertiary treatment and is located at Phinizy Swamp Nature Park**.**
    - After leaving the treatment facility, the wastewater is held in a pond for approximately 3 days to allow the chlorine to evaporate (dechlorination). This step is very important, because chlorinated water would kill the beneficial microorganisms in the wetlands.
    - The water flows from the pond to a manmade wetland through a canal. As described earlier, bacteria, fungi, and protozoa living on the plants in the wetlands consume nutrients (mostly nitrogen) in the water.
    - After traveling through the wetlands, the water is released into Butler Creek. It takes around 10 days for water to go from household drains, through the treatment facility, through the wetlands, and back to the creek.

See page 18 for a diagram of the treatment process in Augusta, GA.

J.B. MESSERLY WATER POLLUTION CONTROL PLANT (WPCP)

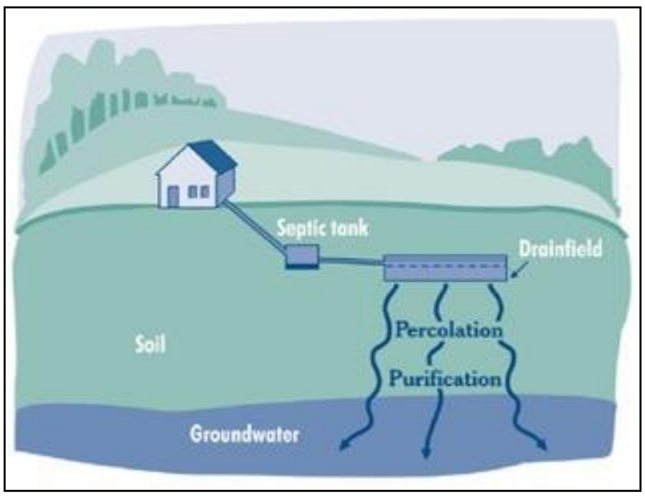


1. **HOMES AND BUSINESSES:** Produce wastewater.
2. **SCREENING:** Removes large debris.
3. **PUMP STATION:** Lifts wastewater.
4. **GRIT REMOVAL:** Removes sand and gravel.
5. **EQUALIZATION BASINS:** Hold excess wastewater.
6. **PRIMARY CLARIFIER:** Removes scum (fats, oils, & grease) and sludge (solid organic waste).
7. **SECONDARY AERATION:** Microorganisms decompose organic material in wastewater and absorb unwanted nutrients.
8. **FINAL CLARIFIER:** Removes microorganisms for return to secondary aeration.
9. **RETURNED ACTIVATED SLUDGE:** Returns active microorganisms to secondary aeration.
10. **DISINFECTION PROCESS:** Removes remaining harmful bacteria.
11. **CONSTRUCTED WETLANDS:** Further treat water before reaching the Savannah River to ensure meeting water quality standards.
12. **DIGESTORS:** Treat wastewater solids to reduce volume and odor, and destroy harmful organisms.
13. **DEWATERING FACILITY:** Removes excess water and prepares solids for beneficial use.
14. **BENEFICIAL USE:** Solids transported for use as fertilizer or safely discarded.

Figure 1.9: A typical wastewater treatment process. Source: Augusta Utilities

Current Septic Systems
Septic systems are commonly used to treat domestic wastewater in rural areas, where long distances between homes make municipal sewer systems inefficient and costly. This is the same reason that most rural homes receive drinking water from wells. Current systems have been greatly improved from the first systems mentioned previously.

- Systems consist of an underground septic tank and a drainfield (typically a home's backyard). Wastewater is piped from the home into the tank, where bacteria digest the waste (See **Figure 1.10**).
- Solids settle to the bottom of the tank and scum (**FOG--**fats, oils, and grease) floats to the top. Solid waste and FOG must be pumped from the septic tank regularly to avoid spilling untreated wastewater into the drainfield and potentially contaminating groundwater. The solid waste pumped from the tank is commonly taken to a municipal wastewater treatment facility for processing. Risers and manholes at the ground surface allow for easy inspection, location, and pumping of the tank.
- The liquid portion of the waste is distributed evenly throughout the drainfield, where it either is taken up by plants or percolates through the soil.



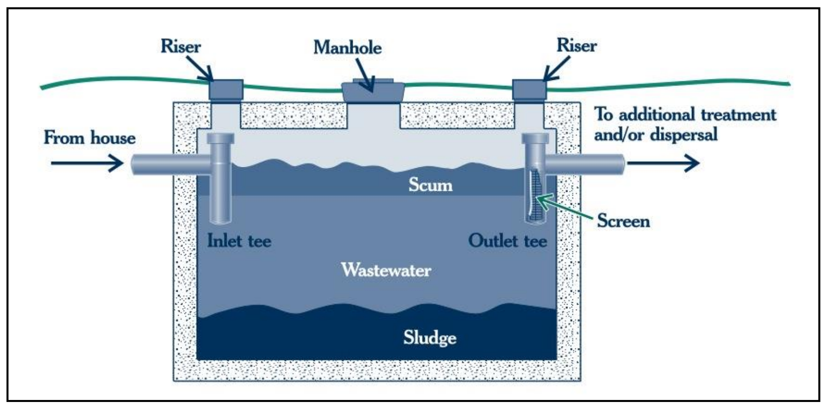


Figure 1.10: Common septic systems. Source: A Homeowner's Guide to Septic Systems, US EPA

Emerging Trends in Wastewater Treatment
Current advancements in treatment technology include:

- Use of reclaimed water for drinking
    - **Reclaimed water** (also known as recycled water) describes wastewater that has been treated to be used for a different purpose, such as landscaping irrigation and industrial water needs.
    - In countries such as Australia, Singapore, and Namibia, and in states such as California and New Mexico, reclaimed water is being used as a source of drinking water. In fact, residents in Namibia (Sub-Saharan Africa's driest country) have been drinking reclaimed water since 1969!
    - After wastewater is treated, it undergoes additional filtration and disinfection to ensure that it is potable.
- Use of methane for fuel

    - Converting sludge to fertilizer using anaerobic digestion by bacteria has been in use for several decades. However, the methane gas produced by the bacteria can also be collected and used for energy.
    - Some wastewater treatment facilities are converting this methane to electricity to power the treatment process. In some areas, this energy is also being used to power homes and businesses.
    - Since using methane for fuel is very expensive, this process is only in use in a small number of facilities around the world. Researchers are currently experimenting with ways to make the process less expensive so it can be adopted in more cities.
- Treatment of pharmaceuticals in wastewater
    - In recent years, concerns have been raised about the levels of pharmaceuticals (such as antibiotics, painkillers, blood pressure medication, and hormone treatments) present in wastewater.
    - These drugs enter the wastewater through human waste, as well as when they are dumped down drains and toilets by people.
    - Most pharmaceuticals present in wastewater are not removed by current treatment methods, and as a result end up in streams.
    - Some drugs can alter hormonal activity in aquatic organisms, causing detrimental effects such as sterility, developmental abnormalities, and death.
    - Traces of pharmaceuticals have even been detected in drinking water.
    - Pharmaceuticals present a unique challenge for wastewater treatment because they persist in the environment and are active at extremely low concentrations.

We hope this study packet has been enlightening! See the timeline on the next page for a list of important milestones in modern drinking water and wastewater treatment. Also use the "Be Sure You Know" page as a refresher
Good luck at Eco-Meet!

Modern Drinking Water & Wastewater Milestones

1804: The first public drinking water facility is built in Scotland. Water is filtered through sand and delivered by horse and cart. (pg. 6)

1854: Dr. John Snow discovers that cholera is spread through contaminated drinking water, leading to separation of wastewater from drinking water sources. (pg. 11)

late 1850s: The first combined sewer systems in the US are built in Brooklyn, NY and Chicago, IL. (pg. 12)

1880: One of the first separate sewer systems in the US is built in Memphis, TN. (pg. 12)

1899: The Highland Ave. Drinking Water Treatment Facility is built in Augusta. (pg. 6)

1899: The **Refuse Act** is passed, making it illegal to dispose of waste in waters used for transportation. (pg. 11)

1914: US Public Health Service sets standards limiting the amount of bacteria in municipal drinking water. Most municipalities have begun treating and disinfecting drinking water by this time. (pg. 6)

1930s: Indoor plumbing is now common-place in the US. Most people in towns and cities have it; some people in rural areas do not. (pg. 10)

1948: The **Federal Water Pollution Control Act** is passed, providing funds to municipalities to build wastewater treatment facilities. (pg. 12)

1960s: Drinking water treatment efforts shift and now include removal of heavy metals, toxins, and industrial chemicals. (pg. 6)

1968: JB Messerly Water Pollution Control Plant is built in Augusta. (pg. 12)

1972: The **Clean Water Act** is passed, requiring all municipalities to build wastewater treatment facilities. (pg. 12)

1974: The **Safe Drinking Water Act** is passed, limiting the amounts of contami-nants in municipal drinking water. (pg. 6)

1996: Constructed wetlands system is built in Augusta as a tertiary step in wastewater treatment. (pg.17)

BE SURE TO KNOW

Water – solid, liquid, gas
Drinking Water
Wastewater
Condensation
Evaporation
Sublimation
Deposition
Surface Runoff
Flow
Subsurface Runoff
Groundwater Flow
Transpiration
Evapotranspiration

Drinking Water:
Potable
Turbid / Turbidity
Raw Water
Pumping Station
Reservoir
Flash Mix
Flocculation
Sedimentation
Filtration Basin
Disinfection
Additives
Desalination

Wastewater:
Cesspits / Privy Vaults
Dilution
Intrastate Waters
Interstate Waters
Preliminary Treatment
Bar Screens
Grit Chamber
Primary Treatment
Primary Clarifier
Scum / FOG / Sludge
Secondary Treatment
Aeration Basin
Activated Sludge
Secondary Clarifier
Disinfection
Chlorination / Ultraviolet / Ozone
Tertiary Treatment
Reclaimed Water
Septic Systems
CSS
SSS

The Refuse Act of 1899 or Rivers and Harbors Appropriation Act

1914 – US Public Health Service Standards

Federal Water Pollution Control Act – 1948

Clean Water Act – 1972

The Safe Drinking Water Act - 1974

Municipality
Infrastructure
Urban Development
Rural Development
Impervious Surfaces