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A Delicate Balancing Act

Disinfecting Water and Wastewater while Portecting Human Health and the Environment
By Ric Jensen
Information Specialist, TWRI

Picture an Olympic gymnest on the balance beam. She wants to perform as well as possible and perform intricate and difficult maneuvers without falling off.

Now picture the plight of many water utility managers when it comes to disinfecting water and wastewater. Their balancing act is to keep the water free of disease-causing organisms without forming by-products that could threaten human health.

Not providing drinking water with enough protection from viruses and bacteria will likely lead to waterborne diseases like cholera and hepatitis that are now being reported along the Texas Mexico border.

Many public health officials say that the benefits of disinfection in preventing water-borne diseases far outweigh any potential health risk. However, some critics charge that the chlorine-based chemicals now most often used to disinfect drinking water can cause increased rates of cancer in humans.

Drinking water has been disinfected in the United States since 1908. Traditionally, chlorine gas and other chlorine-based chemicals have been used in to treat drinking water. For many years, chlorination was the only water treatment practiced in the United States. Because regulations were lax about turbidity, many water plants simply chlorinated without removing suspended particles. Later, other methods of disinfection were developed including ozone, chlorine dioxide, and ultraviolet (UV) light.

Some processes used to disinfect drinking water can combine with organic matterto form trihalomethanes (THMs) and other by products that can cause cancer. A newstudy claims that drinking water disinfected with chlorine can increase the rates of some types of cancer in humans. That article notes that drinking water still needs to be disinfected to prevent the spread of infec tious diseases. "Alternative" disinfectants like ozone and UV light are being investigated that may create fewer by-products. The health risks from byproducts associated with these technologies have not been evaluated.

Drinking water doesn't need to be disinfected only at the production plant. It also needs to be protected against potential contaminants as it flows through the distribution system towards individual users. While many processes provide on-the-spot disinfection, all of the "alternative" processes that do not use chlorine do not produce a long-lasting or residual effect. This may allow bacteria and viruses to contaminate water as it flows through the distribution system.

Wastewater must also be disinfected before it is discharged. Fish and aquatic species that live in rivers and lakes where chlorinated wastewaters are discharged are also vulnerable. Most of us know what happens when we buy a fish at a pet store. The guppy or goldfish is placed in a bag filled with water that doesn't contain chlorine. If that fish is exposed to chlorinated water in your aquarium, it's likely that he will be floating belly up and lifeless in a few hours.

Wastewater treatment plants have been disinfecting effluents with chlorine since the early 1 900s. It wasn't until much later that scientists and regulators began to realize that chlorine wasn't just killing disease causingorganismsÑit was also damaging aquatic species that lived in the waters. In rivers in Texas and elsewhere, it was common to find areas near wastewater plant discharges called "mixing zones" that were nearly void of aquatic life.

As a result, the Texas Water Commission (TWC) now requires wastewater treatment plants with flows of more than 1 million gallons per day (MOD) to remove chlorine before discharging effluents into receiving waters.

In a broad sense, the issue of disinfecting wastewater points out some of the conf licts between recreational and environ mental interests. For example, it may be in the best interest of swimmers to significantly lower the amounts of disease-causing organisms in rivers and streams. When chlorine is used to treat wastewater, the harmful organisms in the effluent are killed. Some argue that chlorinated wastewaters also kill other bacteria in the stream that may have originated from nonpoint sources like fecal matter from livestock or wildlife. However, if chlorine is used as adisinfectant it mayalso produce byproducts that are toxicto f ish and other aquatic species. In that sense, removing the chlorine may benefit the environment. Both of these seem ingly conflicting goals may be achieved if wastewaters could be disinfected with processes that do not produce toxic side effects. Itshould be notedthatthegoalof chlorinating wastewater is not to destroy all the viruses and bacteria in a river, but to remove the disease-causing organisms from wastewater treatment plant effluents.

Many cities with large investments in chlorine-based systems may find it hard to justify the cost of switching to other methods.

This issue of Texas Water Resources will present a broad overview of the risks posed by disinfecting drinking water using chlorine and other methods. We'll also review studies that have assessed the damage to ecosystems caused by chlorinating wastewater. New techniques scientists are using to evaluate if river systems are ecologically healthy will be presented.

Disinfecting Drinking Water

Since U.S. water utilities began disinfecting drinking water in the early 1900s, the number of cases of waterborne diseases such as typhoid, cholera, dysentery, hepatitis and others have declined significantly. In areas where water is not adequately disinfected, outbreaks can still take place. Cholera has recently been reported in Juarez, Mexico, just across the border from El Paso. Residents of colonias along the Texas-Mexico border suffer from high rates of hepatitis. Beforedrinking waterswere disinfected, cholera was a deadly but everyday part of life in much of the world. Even today it plagues many underdeveloped nations.

The most common methods now used to disinfect drinking water involve the use of free chlorine and chloramines (a mixture of chlorine and ammonia). Roughly 90% of the drinking water supplies in the U.S. are disinfected with chlorine or chloramine compared to less than 1% with ozone.

Disinfecting drinking water at the treatment plant is a complicated process that can be accomplished in any number of ways. There are a few general steps that apply for most treatment processes. In systems that use chlorine gas, raw water is dosed with chlorine as it enters the plant. Chemicals are added to form larger and heavier particles that settle out. Fine particles are removed by filtration. A chlorine dose is added to provide additional protection as the water leaves the plant and flows into the distribution system.

By-products that are toxic and/or cancercausing can be formed when chlorine is used to disinfect drinking water that contains high levels of organic materials. Rivers and lakes typically contain higher amounts of organic matter than groundwaters. As a result, more by-products are formed when surface waters are used. More disinfection byproducts are formed in the spring, summer, and fall when levels of organic matter are high. The amount of chlorine used, contact time, pH, and the temperature of the water also influence byproduct formation.

The amount of chlorine used and the time the chlorine is in contact with the water are controlled by TWC regulations. Enough chlorine hasto be added to disinfectthe water inside the plant and to protect it from diseasecausing organisms it encounters as it flows through the distribution system. UV light or ozone may do a good job of disinfecting water in the plant, but may not provide the residual needed to make sure the water will still be disinfected when it arrives at customers' homes. If UV light or ozone are used to disinfect drinking water, it is still required that the water contains a residual disinfectant (usually chlorine or chloramine). Chlorinebased systems may still produce some disinfection by-products as the water f lows throug h the distribution system because of high chlorine levels and long contact times.

The problems are much lesssseverewhen groundwater is disinfected because it contains fewer organic compounds. THM levels in groundwater treated with chlorine can be up to 50 times less than the amounts in surface waters. As a result, many groundwater-based systems still use chlorine gas.

Most large cities in Texas that rely on rivers or lakes treat drinking water with chloramines to minimize the formation of THMs. Many small towns that rely on surface water still use chlorine gas.

State regulations require that drinking water supplies contain less than 100 parts per billion of THMs over a 1 2-month average. The TWC says most utilities are regularly meeting this requirement. Small utilities that serve less than 10,000 people do not have to monitor for THMs.

The U.S. Environmental Protection Agency (EPA) is now considering strengthening its disinfection requirements to further limit the TH M levels allowed in drinking water. Other disinfectant by-products may also be added to the rules.

If the rules are passed as proposed, many public water utilities are expected to switch from chlorine-based disinfectants to other methods. Other options could be to remove disinfection by-products after they are formed but before the drinking water is passed on to customers, or to delay the point where chlorine is introduced into the treatment process.

A solution that's been studied by James Symons, a researcher in the Civil Engineering Department at the University of Houston, is to pre-treat surface waters to remove the organic materials before chlorine-based disinfectants are added. Symons has also studied num erous other aspects of drinking water treatment and byproduct formation.

In El Paso, chlorine dioxide is used in tandem with activated carbon filters to control THMs (Tarquin and Rittman, 1992). The activated carbon reduces the leve ls of organic matter that form THMs while the chlorine dioxide is used as a disinfectant. Chlorine dioxide is also used on the Gulf Coast to disinfect water from the Brazos River.

Risks to Human Health

Determining the health effects of drinking water that has been disinfected with chlorine-based compounds is difficult, in part because contaminants in drinking water are only one of many factorsthatcan harm our health. How do you knowforsure if it was drinking chlorinetreated water over a long period that caused someone to develop cancer? Nearly everyone is involved in many activities that could also threaten their health (for example, smoking cigarettes and eating too many fatty foods).

The most dangerous and widely studied disinfection by-products are THMs. Other disinfection by-products include organic acids, ketones, aldehydes and alcohols.

THMs are formed by interactions between chlorine, bromine, and organic matter. Studies have shown that rats, mice and dogs exposed to THMs may suffer from irreversible liver and kidney damage. Other research shows that chloroform causes cancer in rats end mice. Thereisdisagreementoverwhether chloroform causes cancer in humans.

One very toxic disinfection by-product that has recently been identified is MX (chlorohydroxyfuranone). Until recently, little attention was focused on MX because it is unstable and difficult to measure.

Just how harmful are these by-products? The answer varies depending on who you talk to. Chlorinated drinking water is not classified as acarcinogen bythe International Agency for Research on Cancer because epidemiology data are inadequate to determine its carcinogenicity. The EPA agrees with that assessment.

However, a recent analysis of 10 earlier studies concluded that 18% of all cases of rectal cancer and 9% of all bladder cancer cases in the U.S. annually may be linked to consumption of chlorinated drinking water containing THMs (Morris and others, 1992). Other studies suggest that surface waters treated with chlorine may increase the risk of some types of cancer.

Research by Ahmed Ahmed of the University of Texas Medical Branch at Galveston suggests that chlorinated drinking water may cause increased rates of cancer. Ahmed conducted a 1 0-year study in which rats were exposed to chlorination by-products called haloacetonitrites (HANs). HANS are formed when chlorine reacts with algae and other impurities during watertreatment. More than 37% of the HANs remained in gastrointestinal tissues, reducing the digestive system's defense against toxicity and disease.

Bill Batchelor of the Civil Engineering Department at Texas A&M University is developing a computer model to help predict when disinfection by-produc ts like THMs and others would form and in what amounts. The model bases its estimates on reactions between free chlorine and the amounts of organ ic materials and othe rfactors that combi ne to form various disinfection by-products. Researchers hope this could be useful in everyday operations for water utilities.

Alternative Disinfectants

In response to health concerns posed by chlorinated by-products, some areas in Texas and elsewhere are now using methods such as ozone, UV light, and chlorine dioxide to treat their drinking water.

The City of Fort Worth is developing one of the first municipal drinking water treatment plants in Texas that will use ozone. Ozone may be less likely to cause harmful by-products than chlorine or chloramine.

Some critics charge that these methods do not disinfect as well as free chlorine and that they too may produce unhealthy byproducts (Johnson and Jolley, 1990). Conversely, other studies (Anderson and others, 1990) suggest that disinfecting with free chlorine produces more disinfection by-products than chloramines, chbrinedioxide, and ozone.

Disinfecting Wastewater

In Texas, wastewater treatment plants with flows of more than 1 MGD are now being required by the TWC to dechlorinate their wastewater effluents because of new revisions to the Clean Water Act. This is part of a program to reduce the toxicity of wastewater discharges to fish and other aquatic organisms that live in to rivers and streams. The TWC and the EPA set targets for the amount of residual chlorine that can be allowed in wastewaters.

The State is also trying to lower levels of bacteria in surface waters to make waters fishable and swimmable. Chlorinated wastewaters may continue to kill germs in surface waters. Dechlorinating wastewater may boost bacteria levels in rivers and streams.

TWC regulations also provide that fish and other species be allowed to safely swim through areas called "zones of passage." These sites are located on the bank of a river or stream on the opposite side of wastewater discharges. These areas often can not support aquatic life if the volume of effluents or contaminant levels in the effluent are high.

Many plants that use chlorine to disinfect wastewater are adding sulfur-based compounds to remove the chlorine. A problem experienced by utilities in Houston is that adding sulfur dioxide increases oxygen demands and lowers oxygen levels in bayous and streams. Low oxygen levels often will not support aquatic ecosystems (Garrett, 1991).

Some utilities are pursuing alternative technologies. For example, the Trinity River Authority's Denton Creek plant is disinfecting with UV light. Wastewaters flow into an area where4banksofUVlights are arrayed. Each bank has 64 lamps. Wastewaters are exposed to the lights for 20 minutes before being released. The lamps are cleaned every three months to remove algae growth and to maintain their intensity. The plant is economical because it requires less than 10% of the area needed for a chlorine-based plant and because chemical costs are rising.

Alternative ways of disinfecting wastewater involve the use of ozone or other chemicals such as chlorine dioxide or bromine chloride. El Paso injects highlytreated wastewater into the ground to replenish groundwater supplies that will eventually be used for drinking water. Ozone is used to initially disinfectthe wastewater, while small amounts of chlorine are added to prevent contamination after the water has been injected.

Some industries are required to dechlorinate wastewaters before discharging them into receiving streams. Some of them are using hydrogen peroxide. This will probably not be a useful technique for most municipal plants that disinfect with chlorine. This is because ammonia, a common component of municipal wastewaters, reacts with chlorine to form chemicals that hydrogen peroxide cannot remove.

Disinfection Methods		
Method	**Advantages**	**Disadvantages**
Free Chlorine	Provides a residual, (Chlorine Gas) potent germ killer, reduces bad tastes and odors	Can cause harmful by-products to form if organic matter is present; can be dangerous to work with; may not work with waters with high pH
Chloramines	Creates fewer harmful by-products, provides a residual, reduces bad tastes and odors	Requires increased dosages and contact times, may be less effective than chlorine at killing viruses and germs; may not work with waters with high pH
Ozone	Excellent at killing viruses, reduces THM precursors, controls bad tastes and odors	Produces its own set of potentially harmful by-products, no long-lasting residual; costs may be high
UV Light	No chemical storage or handling required, no known disinfection by-products produced	No residual action, ability to disinfect can be compromised by water clarity, hardness, and power failures; costs may be high
Chlorine	Reduces bad taste and Dioxide odors; provides a strong residual; strong disinfectant	Produces toxic inorganic byproducts

Impacts on Aquatic Species

Many experts believe that chlorinated wastewaters negatively impact receiving waters. However, it's hard to separate the effectsof chlorine from those of other toxic chemicals that are intermingled in the waste stream and low oxygen levels .

In Texas, much of the research on the impact of wastewater on receiving streams has focused on the Upper Trinity River. The area has been plagued by recurring fish kilis and the river is effluent-dominated during low and normalflows. Researcherswith the U.S. Fish and Wildlife Service (USFWS) placed golden shiners and fathead minnows in cages downstream from wastewater plants in Dallas and Fort Worth. Some plants dechlorinated their effluents while others discharged chlorinated wastewater. Results showed that wastewaters that had been dechlorinated were not acutely toxic. Chlorinated effluents killed fish as far as 5 miles downstream from wastewater discharge points (Dean, 1988).

Studies by the Texas Parks and Wildlife Department (TPWD) show that fisheries just downstream of the Dallas Central Wastewater Treatment Plant were much less healthy than in other reaches of the river, mainly because of chlorine and ammonia toxicity (Kleinsasser and Linam, 1989 and 1992). Similar results were found in TWC studies (Davis, 1991).

The University of North Texas (UNT) is conducting a comprehensive study to measuretheeffects of dechlorination onthe physical, chemical and biological water quality of the Upper Trinity River. The study involves more sampling stations near wastewatertreatment plants and other critical areas. Preliminary results suggest that dechlorination will improve the survival of many fish species, but that some macroinvertebrates like daphnia (a waterflea) may still be impacted by other toxics in the river (Guinn and others, 1992).

Studies focusing on the impact of chlorinated wastewater on aquatic ecosystems in the Guadalupe and San Marcos Rivers have been undertaken by scientists at Southwest Texas State University. Glenn Longley, Marc Bentley, and Vijay Chakravarthy compared the short- and long-term toxicity of effluents from three wastewatertreatment plants. Two of the plants disinfect wastewater with chlorine before discharging. The study found that wastewaters disinfected with chlorine were extremely toxic, while those that were not chlorinated were not toxic (Bentley, 1990). Free chlorine was more toxic to aquatic organisms than chlorinated by-products.

Other studies (Cairns and others,1990) have compared the toxicity, persistence, and fate of residual chlorine in rivers and streams. Results found that the combined effects of chlorine and ammonia were substantially more damaging than the individual effect of either chemical. The growth and survival of some species was limited.

Measuring Ecosystem Health

Just how do you know if the water quality in a river is high enough to sustain fish and other species? A number of techniques are nowbeing used that measure water quality by examining the amounts and types of species found at various points along a water body.

One of the most commonly used methods is the Index of Biotic Integrity (IBI). In this technique, samples of fish and other aquatic species are taken at different sites along a river. The samples are grouped by the type of species. Species are categorized by what they eat (vegetation, insects, and/or other fish) and by whether they are sensitive to pollution. For example, some fish like carp will iive in almost any Texas river or stream including those that are highly polluted. Finding them wouldn't tell you much about water quality. On the other hand, fish like darters and invertebrates like mayflies only live in high quality water. If you find them, the water can't be too polluted. IBI scores are generated for each reach of the stream and can be used to designate key parts of a river as having high, intermediate or low ecosystem health. Studies by the TPWD (Kleinsasser and Linam, 1989) gave the lowest IBI scores along the Upper Trinity River to areas immediately below wastewater treatment plants.

Follow-up studies by the TPWD (Kleinsasser and Linam, 1992) examined if dechlorinating wastewater effluents in the Upper Trinity River improved conditions for aquatic life. Substantial improvements were found in species richness and populations downstream of wastewater plants that dechlorinated their discharges. Chlorine concentrations dropped to low levels, but fecal coliform counts increased.

An IBI technique that will use Texasspecific species is now being developed by the TPWD and the TWC. In most IBI studies, species are used that are significant nationally but these species may not be found routinely in Texas. The Texas IBI should more accurately judge the relative health of Texas rivers and streams.

Scientists at UNT are developing similar techniques to determine how stream-based ecosystems may be affected by chlorinated wastewater and other toxics.

Thetechnique consists of taking samples of fish, macroinvertebrates, zooplankton and phytoplankton at sites above and belowwastewater plant discharges. Sites above the plant serve as reference sites relatively unaffected by the discharges while those immediately downstreambearthefullbruntofthepollution (Dickson and others, 1992).

Information gained from the studies is being analyzed and may be used to predict how characteristics of effluents may affect a wide spectrum of species.

Summary

The benefits of disinfecting water and wastewaterare well documented. Obviously, drinking water and wastewater still need to be disinfected. Supplying drinking water that has not been properly disinfected would increase the number of water-borne diseases caused by viruses and other pathogens. One official, when asked if it would be hard to estimate the effect of no longer disinfecting water and wastewater, replied it would be easy. "Just count the body bags," was his terse reply.

On the other hand, if the methods now being used to disinfect drinking water are increasing the rates of cancer and other human health risks, those techniques must be reexamined. Other ways of disinfecting drinking water that may be more safe should be studied. Particular attention needs to be paid to those methods that provide excellent disinfection (both at the plant and in the distribution system) and minimize the formation of dangerous byproducts.

The benefits of removing disinfectants from wastewaters are also becoming more apparent, especially in the Upper Trinity River. If we can improve conditions for fish and other aquatic species while not compromising human health, this is a laudable goal.

The impact of dechlorinating wastewater plant effluents on bacteria levels in rivers and streams also needs to be carefully evaluated.

Techniques like the IBI are tools that resource managers can use to gauge how pollution is actually affecting aquatic species in their natural environments. By telling us more about real world conditions, they can help us develop appropriate water quality standards and protection measures.

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