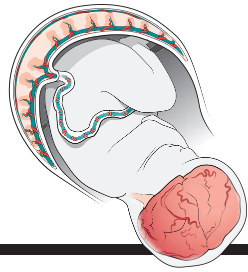
INSIGHTS

Chiral catalysis with ion pairs *p. 918*

Maternal infection and brain development *p. 919* ▸



PERSPECTIVES

Getting a drink. Countries around the world differ in their approach to delivering safe drinking water to their citizens. The photo shows a young boy drinking from a waterfront tap in Guam, USA.

WATER INFRASTRUCTURE

How do you like your tap water?

Safe drinking water may not need to contain a residual disinfectant

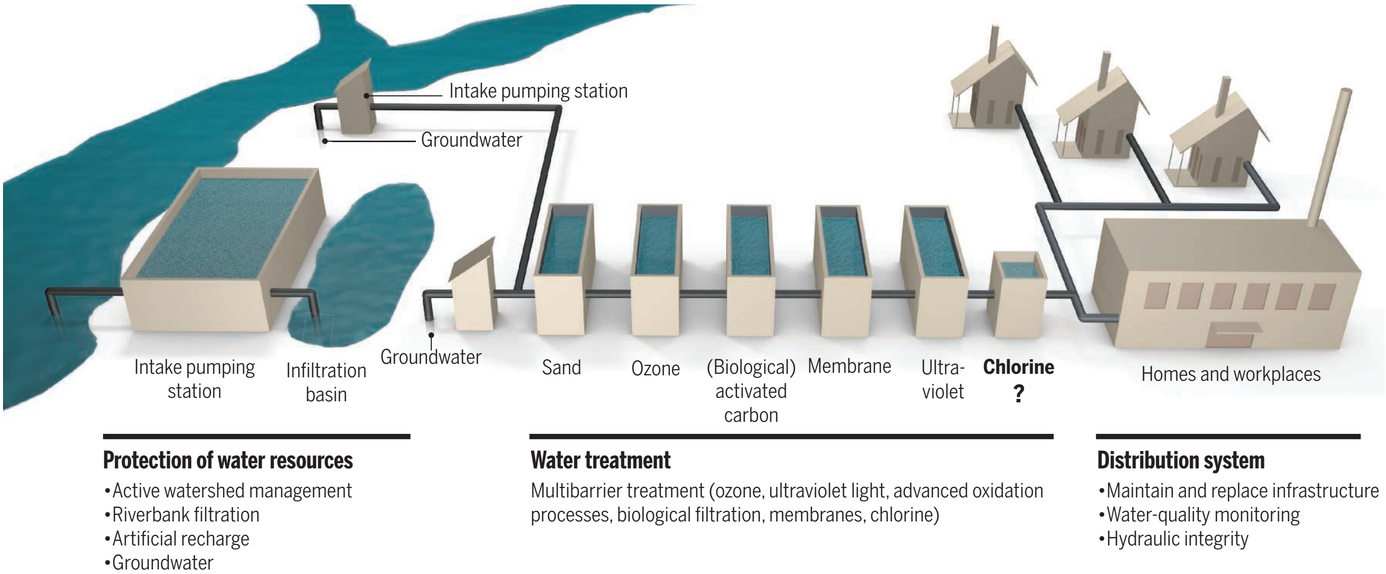
By **Fernando Rosario-Ortiz,[1,2] Joan Rose,[3] Vanessa Speight,[4] Urs von Gunten,[2,5] Jerald Schnoor[2,6]**

The expectation that tap water is safe has been sorely tested by the recent events in Flint, Michigan, where lead contamination has caused a public health emergency (*1*). Apart from contamination with heavy metals and other harmful substances, a key concern is the control of microbial contamination. To prevent microbial growth and protect consumers from pathogens from other sources, some countries, such as the United States, require the presence of residual disinfectant in drinking water. However, the presence of a disinfectant can lead to the formation of potentially carcinogenic disinfection byproducts, issues with corrosion, and complaints based on the fact that people dislike the taste of disinfectants in their water (*2*). The experience of several European countries shows that such residual disinfectants are not necessary as long as other appropriate safeguards are in place.

From the early 1900s, the control of microbial waterborne pathogens, including *Salmonella typhi* and *Vibrio cholera,* led to a major reduction of waterborne diseases in the industrialized world. Filtration and chlorine disinfection reduced mortality in the United States substantially. But in 1974, chloroform, a probable human carcinogen formed by the reaction of chlorine with naturally occurring organic matter, was discovered in chlorinated drinking water. This discovery led to a debate about microbiological safety versus exposure to harmful substances, and the overall effectiveness of disinfectants in the distribution system (*3*, *4*). Furthermore, disinfectants can contribute to the leaching of lead from pipes in older distribution systems (*5*).

In some European countries (including the Netherlands, Switzerland, Austria, and Germany), drinking water can be delivered to consumers without a residual disinfectant as long as there is adequate source protection, treatment, and maintenance of the distribution system to prevent growth of pathogenic bacteria and additional contamination events (see the figure). If one of these elements is missing or improperly managed, disinfectants are added to the distribution system to maintain a residual and a margin of safety.

In the United States, unprotected surface waters often serve as source water. Treatment includes coagulation, sedimentation, filtration, and disinfection with specific contract times. The water is then distributed to the consumer with a residual chemical disinfectant (chlorine, chlorine dioxide, or chloramines) as a last barrier against contamination.



Multibarrier approach to drinking water safety. Filtering through soil and/or sand-gravel aquifers protects source waters from many microbial contaminants. Well-controlled water treatment includes particle removal, disinfection, biological filtration, and removal of natural organic matter. Water can then be distributed to consumers without addition of a disinfectant residual, but with the capacity to do so in the event of leaks or repairs.

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The choice between the two approaches is based on balancing the risk of microbial contamination, exposure to disinfection byproducts and the taste and odor of chlorine. In western Europe, eliminating the use of disinfectant during distribution certainly limits the formation of disinfection byproducts, but does it result in increased incidence of disease? And in the United States, how effective is maintaining a disinfectant residual in reducing the frequency of disease outbreaks? Also, what level of investment is needed to limit problems associated with old infrastructure, such as in the case of Flint? Estimates have ranged from tens of millions to $1.5 billion USD for Flint alone, and many other cities have similar infrastructure problems.

There is little direct evidence that disinfectant residuals have prevented drinking water–related disease outbreaks (including aerosol-associated cases of *Legionella*). A comparison of waterborne disease outbreak data from the Netherlands, United Kingdom, and United States shows that the Netherlands has a very low risk of waterborne disease. For these three countries, the rates of outbreaks per 1000 population in the last few years were 0.59, 2.03, and 2.79, respectively (*6, 7*). It seems that the presence of a disinfectant in the distribution system does not guarantee lower rates of disease outbreaks. However, small groundwater systems that are not chlorinated and are typically used intermittently have caused the most recent outbreaks in the United States (*6*).

An additional consideration in the debate about disinfectant residuals is the robustness of the infrastructure against contamination events. In the Netherlands, at least half of the water distribution pipes have been replaced since the 1970s; as a result, pipe networks are, on average, 33 to 37 years old (*8*). Although there are regional differences, an estimated 22% of the pipes in the United States are more than 50 years old; the average age of pipe at failure is 47 years, and only 43% of pipes are considered to be in good or excellent condition (*9*). In the United Kingdom, as much as 60% of pipe inventory does not have a record of pipe age, and estimates of average pipe age are on the order of 75 to 80 years overall (*10*). The use of a disinfectant residual is required in the United Kingdom (*11*).

Leakage is one measure of vulnerability of the distribution system. It is as low as 6% in the Netherlands, compared to 25% in the United Kingdom and 16% in the United States (*8, 12, 13*). Generally, United States distribution systems have longer retention times, which may promote microbial regrowth and disinfection byproduct formation. Maintenance of adequate pressure can provide a barrier against contaminant intrusion, but excessive water pressure, including transients, can lead to pipe breaks. In fact, drinking water infrastructure in the United States is in serious need of investment, including the replacement of lead-lined pipes or connections that are found in many households.

It should be noted that there are differences in drinking water costs between Europe and the United States. Water prices in some western European countries are on average two to three times higher than in the United States (*14*). It is clear that pricing for potable water also needs to be evaluated to determine how much should be spent to ensure microbiological safety and integrity of the distribution system.

To understand the long-term properties of water distribution systems, comparative data are needed on water quality, disease outbreaks, and distribution system failures from all approaches used to produce potable water. The water microbiome in distribution pipes and the definition of microbiologically safe water should be further investigated. In addition, improved monitoring and emerging sensor technology can provide warnings and alerts, helping to determine when to restore and protect extensive pipe assets. In the case of green water infrastructure, which includes water recycling, rainwater harvesting, and solar water heating, multiple barriers will be necessary to prevent opportunistic pathogens such as *Legionella*, which is higher in buildings with green water designs and longer water residence times (*15*). But the European evidence to date suggests that safe water can indeed be delivered without a disinfectant residual, as long as there are multiple barriers in operation. ■

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WATER

Saving freshwater from salts

Ion-specific standards are needed to protect biodiversity

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Many human activities—like agriculture and resource extraction—are increasing the total concentration of dissolved inorganic salts (i.e., salinity) in freshwaters. Increasing salinity can have adverse effects on human health (*1*); increase the costs of water treatment for human consumption; and damage infrastructure [e.g., amounting to \$700 million per year in the Border Rivers catchment, Australia (*2*)]. It can also reduce freshwater biodiversity (*3*); alter ecosystem functions (*4*); and affect economic well-being by altering ecosystem goods and services (e.g., fisheries collapse). Yet water-quality legislation and regulations that target salinity typically focus on drinking water and irrigation water, which does not automatically protect biodiversity.

POLICY

For example, specific electrical conductivities (a proxy for salinity) of 2 mS/cm can be acceptable for drinking and irrigation but could extirpate many freshwater insect species (*3*). We argue that salinity standards for specific ions and ion mixtures, not just for total salinity, should be developed and legally enforced to protect freshwater life and ecosystem services. We identify barriers to setting such standards and recommend management guidelines.

Attempts to regulate salinization on the basis of ecological criteria can be found in the United States and Australia, where total salinity recommendations have been made (*5*, *6*). Even these criteria are insufficient to protect freshwater life, because waters with the same total amount of salts but different ionic composition can have markedly different effects on freshwater fauna (*7*). Canada and the United States are the only countries in the world that identify concentrations of a specific ion (chloride) above which freshwater life will be harmed (*6*, *8*). Globally, concentrations of other ions (e.g., Mg^{2+}, HCO_3^-) remain free from regulation in spite of their potential toxicity (*9*).

The situation will likely worsen in the future, because predicted increase in demand for freshwater will reduce the capacity of surface waters to dilute salts, and increasing resource extraction and other human activities (*10*) will generate additional saline effluents and runoff. Climate change will likely exacerbate salinization by causing seawater intrusion in coastal freshwaters, increasing evaporation, and reducing precipitation in some regions (*11*).

SETTING STANDARDS. Scientific understanding of mechanisms by which increasing salinization damages freshwater ecosystems is in its infancy, which makes it challenging to develop and implement standards protective of freshwater life. Technical challenges are exacerbated by the fact that salinization risks perceived by the public and policy-makers may be much lower than those identified by scientists. In addition, although scientific input has been

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