United States
Environmental Protection
Agency

Office of Research and
Development
Washington, DC 20460

EPA/640/K-94/003
May 1994

EPA

Drinking Water Treatment for Small Communities

A Focus on EPA's Research

EPA's Office of Research and Development

The Office of Research and Development (ORD) conducts an integrated program of scientific research and development on the sources, transport and fate processes, monitoring, control, and assessment of risk and effects of environmental pollutants. These activities are implemented through its headquarters offices, technical support offices, and twelve research laboratories distributed across the country. The research focuses on key scientific and technical issues to generate knowledge supporting sound decisions today, and to anticipate the complex challenges of tomorrow. With a strong, forward-looking research program, less expensive more effective solutions can be pursued and irreversible damage to the environment can be prevented.

Drinking Water Treatment for Small Communities

A Focus on EPA's Research

The U.S. Environmental Protection Agency (EPA) projects that new drinking water standards will help prevent hundreds of thousands of cases of disease each year and will provide increased health protection for all Americans served by public water systems. The new standards include requirements for increased water utility monitoring of water quality to ensure its safety. Where contaminants are present at levels exceeding the standards, utilities will need to provide treatment. Many utilities will need to upgrade existing treatment facilities or design new ones, and tens of thousands of small systems (3,300 or less population served) may find it difficult to meet the new requirements.

To address these needs, EPA's Office of Research and Development (ORD) is working with industry, states, and communities to adapt alternative treatment technologies to smaller scale to ensure that regulatory requirements can be met cost-effectively and realistically by even the smallest jurisdiction.

This effort focuses on treatment technologies for small systems, including prefabricated central treatment systems (package plants) and home treatment units, to reduce biological, chemical, and radiological contaminants to acceptable levels in water supplies. Small communities throughout the nation with differing raw water qualities are participating in ORD's studies to test and evaluate treatment technologies. Results to date indicate that small systems can upgrade drinking water quality at a reasonable cost.

Water Use

Americans use about 12 billion gallons per day in public water supplies. This demand is filled by the nation's abundant fresh water resources in over 2 million miles of streams, 30 million acres of lakes and reservoirs, and huge underground aquifers (subsurface geologic formations that store water). About 50 percent of the population receives drinking water from surface water supplies and 50 percent from ground water sources. Most large cities use surface water as their drinking water source, but small towns or communities with populations of less than 3,300 most often use ground water. Currently, about 50 percent of ground water supplies are disinfected. However, with new regulations, disinfection of all ground waters will be required to inactivate organisms or microbial contaminants, called pathogens, that produce disease. About 13 million people (5 percent of the population) draw water from private wells, which are not federally regulated under the Safe Drinking Water Act .

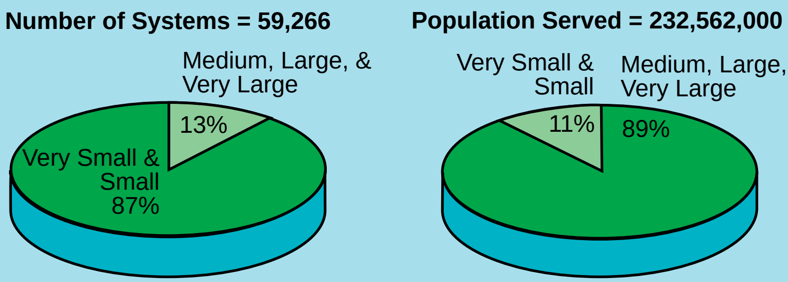
The majority of our nation's water suppliers are small systems serving 25 to 3,300 people. Eighty-seven percent of community water systems serve only 11 percent of the community system population, and two thirds of all systems serve communities of fewer than 500 people. Small and very small community water systems serve fewer than 26 million of approximately 233 million customers in the country.

Many small systems will find it difficult to comply with new environmental regulations because they cannot afford the necessary equipment or staff for treatment. As additional contaminants are identified in drinking water and standards are developed, the complexity of managing water systems, especially for small systems, will increase greatly.

Sources of Contamination

Treating water supplies to remove health-threatening contaminants is costly. Some pollutants are

Community water systems.



System Size and Population Served: Very small (25-500): Small (501-3,300); Medium (3,301-10,000); Large (10,001-100,000); Very Large (More than 100,000) harmful in small amounts, and can be difficult to remove once they have contaminated a water supply. Many occur naturally in the earth's crust (geological), such as arsenic, fluoride, and radionuclides. Other potential sources of contamination include failures in septic tanks, sewer systems and municipal landfills; pesticides and fertilizers spread on cropland and lawns; highway salt; and industrial and municipal wastewater facilities that discharge into surface waters. Poorly constructed or improperly abandoned wells provide pathways for contaminants to enter aquifers. Unless managed properly, all of these sources have the potential to pollute.

Regulations

Concern about the quality of the nation's drinking water supplies prompted the Safe Drinking Water Act legislation in 1974. The EPA is authorized to design national standards that are the primary responsibility of the states to enforce. The Safe Drinking Water Act has had a significant effect on improvements in both water quality and water supply management. Increasing concerns with toxins in the drinking water led Congress to amend the

Examples of health risks from the tap.

Contaminants	***Health Effects***	***Sources***
Microbiological	*Acute gastrointestinal illness, dysentery, hepatitis, typhoid fever, cholera, giardiasis, cryptosporidiosis, etc.*	*Human and animal fecal matter*
Arsenic	*Dermal and nervous system toxicity*	*Geological*
Lead	*Central and pheripheral nervous system damage; kidney effects; highly toxic to infants and pregnant women*	*Leaches from lead pipes and lead-based solder, pipe joints*
Nitrate	*Methemoglobinemia ("blue baby syndrome")*	*Fertilizer, sewage, feed lots*
Fluoride	*Skeletal damage, dental fluorosis*	*Geological*
Pesticides and herbicides	*Nervous system toxicity, cancer risk*	*Farming, horticultural practices*
Trihalomethanes	*Cancer risk*	*Treatment by-product*
Radionuclides	*Cancer*	*Geological*

original Act in 1986, making it stricter and more inclusive.

National Drinking Water Standards

The Safe Drinking Water Act has two parts. First, EPA is to establish National Primary Drinking Water Regulations for drinking water quality. Generally these standards are numerical criteria for each contaminant that may be found in a drinking water supply and that may have an adverse effect on health. Drinking water standards establish maximum contaminant levels, the highest allowable concentration of a contaminant in drinking water. The maximum contaminant levels are determined through risk assessment procedures that take into consideration health effects, treatment technologies, sampling techniques, monitoring requirements, and appropriate management practices. Maximum contaminant levels are usually expressed as milligrams per liter (mg/L), which are equivalent to parts per million, since one liter of a substance contains one million milligrams.

Under certain conditions, EPA may designate that a treatment technique be used in place of a maximum contaminant level. The Surface Water Treatment and Lead and Copper Rules require a treatment technique instead of a maximum contaminant level.

A community water supplier is a utility that provides drinking water to 25 or more people. There are just under 60,000 community water suppliers, but only about 250 of these suppliers serve populations of 100,000 or more. Non-community drinking water suppliers — motels, resorts, restaurants and similar establishments, number about 140,000 and serve non-residential users.

Monitoring Supplies

The second part of the Act pertains to water suppliers. The operators of the 200,000 public water systems in the country will monitor the quality of the water delivered to consumers and treat that water if necessary to assure that the concentration of each contaminant remains below the acceptable levels established by EPA.

Monitoring requirements differ according to whether the system is a community or non-community supply. Community and regional water supplies are developed, owned and operated by various government agencies or private groups. Other commercial concerns, such as trailer parks or hospitals often supply water as an ancillary service. These suppliers must meet some or all of the federal drinking water regulations.

New Requirements

The 1986 Amendments greatly extended federal, state and local responsibilities for protection of community water supplies. Water utilities must provide the necessary facilities, personnel, and operating vigilance to assure delivery of an adequate supply of safe water that consistently meets the requirements of the National Primary Drinking Water Regulations. In addition, they have various decision-making responsibilities beyond direct operation and maintenance. They are subject to increased public scrutiny since the public must be notified of each drinking water violation, and they are subject to more frequent and larger fines for violations.

Drinking water standards must be met in the near future for 108 contaminants, which include biological contaminants, pathogenic bacteria, viruses, protozoa, etc.; lead; radionuclides; by-products of disinfection; organic chemicals; and nitrates and other inorganic chemicals. Monitoring will also be required for a number of unregulated parameters. Monitoring requirements

Protection Programs- The Safe Drinking Water Act provides several programs that establish environmental safeguards to prevent contaminants from reaching water sources.

•To assess and protect ground water sources:

Wellhead Protection Program - identifies all potential contamination sources within an area surrounding a community water supply well.

Sole Source Aquifer Demonstration Program - prescribes a comprehensive land management plan that can be used to eliminate activities that have an adverse impact on public health and ground water within the area surrounding a community supply well.

•To protect surface water supplies:

Watershed Control Program - restricts activities that have the potential to contaminate surface waters. The goal of the program is to preserve and improve raw water quality by identifying and controlling contamination sources in the watershed.

for each contaminant are quite specific, and water systems must follow a prescribed schedule and procedure for contaminant sampling and analysis. However, states have the authority to waive monitoring requirements for many contaminants if those substances have never been used in an area or if water systems are not vulnerable to contamination by the substance.

Best Available Technology

The regulations designate the best available technology for each contaminant exceeding standards to bring drinking water systems into compliance. The best available technologies are intended to assist EPA in establishing maximum contaminant levels by taking into consideration the various treatment technologies available, their cost and efficiency for removing contaminants from water, and to aid water utilities in selecting appropriate treatment methods to meet drinking water standards.

The ORD provides supporting information on performance and cost of treatment technologies for maximum contaminant level or rule development.

Research Strategy

As a result of amendments to the Safe Drinking Water Act, EPA estimates that more than 6,000 water systems will have to install water treatment to meet the proposed standards for organics and inorganics, 11,000 systems will be affected by filtration requirements, and 43,000 systems must address corrosion control alternatives.

Under the Safe Drinking Water Act, water utilities, EPA, and states have enormous responsibilities. The agenda for EPA to establish, states to regulate, and utilities to

Tub from an old washing machine was used to filter large particles from a very small community drinking water supply. The Safe Drinking Water Act, as reauthorized, sets requirements for filtration that cannot be met with such homemade devices.

Risk Reduction Engineering Laboratory

Much of EPA's drinking water research is conducted by ORD's Office of Environmental Engineering and Technology Demonstration at the Risk Reduction Engineering Laboratory's Drinking Water Research Division in Cincinnati, Ohio. This staff has provided leadership in drinking water research for several decades. Their work in microbiological treatment and in inorganics and organics control has contributed significantly to advancing the state of the science in these areas.

Through a multidisciplinary program, integrating chemistry, engineering, microbiology, and economics, drinking water research is conducted to establish practices for the control and removal of contaminants and for prevention of water quality deterioration during storage and distribution. This research is directed toward improving chemical removal methodologies, controlling disinfection by-products, evaluating disinfection processes, and providing technical assistance to states and municipalities in adopting and implementing drinking water standards. In-house pilot plant treatment facilities aid the testing and evaluation of new and emerging technologies for potential real-world application.

This Laboratory, in support of EPA's National Water Program, is concentrating much of its effort exploring new or improved and more affordable technologies for small communities.

meet a multitude of regulatory requirements will demand solutions to many new and complex problems.

Small Systems

To bring small community systems into compliance will necessitate some new thinking and flexibility in terms of technology applications and institutional arrangements. Treating 50,000 gallons per day is not simply a matter of downsizing to one percent of a 5-million-gallon per day plant. Operator ability, capital resources, and extremes in water quality must be taken into account.

The treatment needs of small utilities often are not clear. Pilot testing programs to evaluate treatment processes and operations on a small scale contribute significantly to final system design and success. The innovative application of proven techniques and technologies in individual plants and units may provide solutions to most small community water quality problems.

Package Plant Systems

The most significant requirements for small systems are low construction and operating costs, simple operation, adaptability to part-time operations, and low maintenance. To meet these needs, the less costly package plant systems present an attractive alternative to small custom designed central treatment systems. The difference between package plants and custom designed plants is that package plants arrive on site virtually ready to operate.

Most of the technologies used in custom designed treatment plants for community water systems can be used in package plants and home treatment units. These technologies are applied to reduce levels of organic contaminants and control turbidity, fluoride, iron, radium, arsenic, nitrate, microorganisms and many other contaminants. Aesthetic parameters such as taste, odor, or color also can be improved.

Researchers in ORD are working to provide an analysis of package plant treatment systems to determine performance, costs, reliability, and capability. A great deal of this effort is focused on encouraging industry to design and make prefabricated small treatment plants suitable to the sizes and various treatment needs of small communities. Prefabrication means lower on-site construction costs. To complete this work, ORD will create and demonstrate hybrid package plant designs and configurations.

Operation and Maintenance

Through a cooperative effort with the American Water Works Association (AWWA), ORD has been examining the broad application and use of package plants across the country. This study,

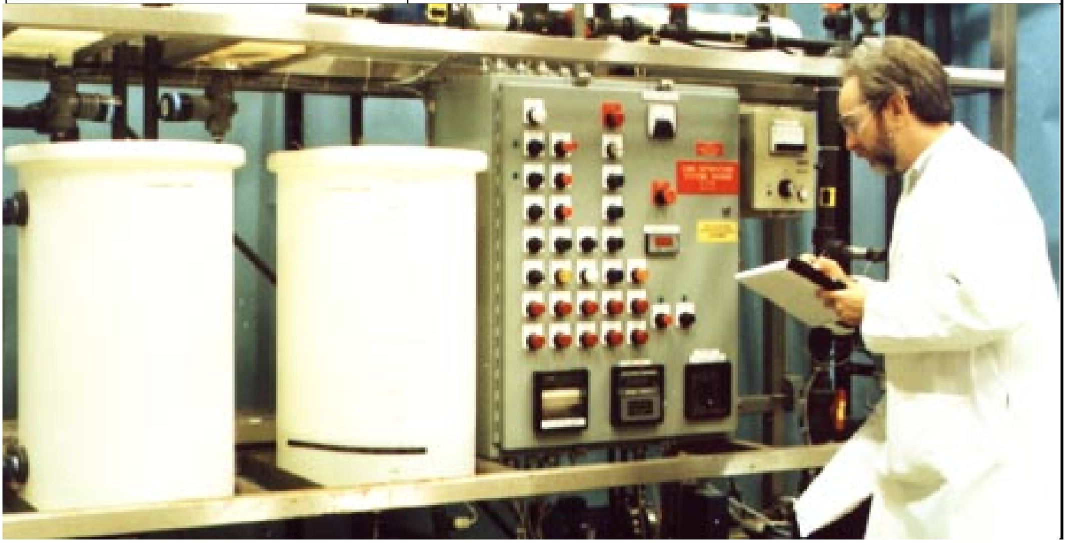
Package Treatmant Plants

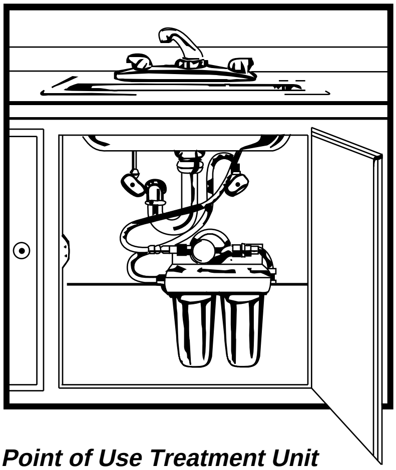
Package plants are treatment units that are assembled in a factory, mounted on a skid, and transported to the treatment site, or alternatively, transported as component units to the site and then assembled. They are currently most widely used to treat surface water supplies for removal of turbidity, color, and microbes with filtration processes. However, most treatment technologies are adaptable to package plant design and configuration.

Design criteria and operating and maintenance requirements can vary widely. Thus, there is a need to develop reliable data and knowledge of package plant systems to enable development of appropriate guidance on selection criteria.

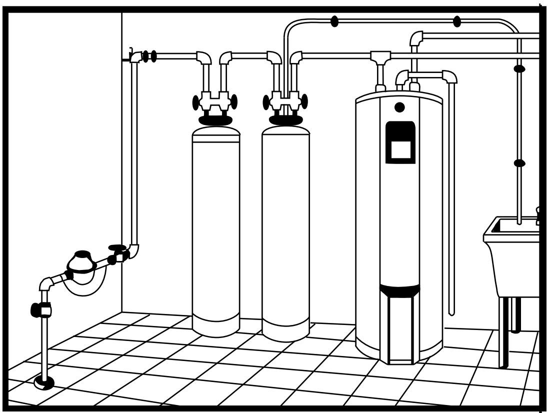
The ORD is working with plant manufacturers to test different package plants at their Test and Evaluation (T & E) Facility, located in Cincinnati, Ohio. The plants to be tested focus on disinfection and removal of organic material to improve the disinfection process, since this is the area of greatest concern and subject of the pending Disinfection/Disinfection By-Product and Surface Water Treatment Rules. In addition, alternative disinfectants will be tested via a nearly full-scale pipe loop system to evaluate water quality as it is delivered to the tap through the distribution system.

Ultrafiltration membrane package plant undergoing tests at EPA's Test & Evaluation Facility in Cincinnati, OH.





Point of Use Treatment Unit



Point of Entry Treatment Units

Home Treatment Units

Home treatment units can be an alternative to centralized treatment technology for individual and small systems. Such systems have been widely adapted to treating water from a single faucet at the point of use or for the entire house at the point of entry. Their off the shelf availability makes them attractive alternatives. Very small systems may find point of entry units less costly to buy and easier to install and maintain than a custom designed or package plant. For example, a responsible party at a Superfund site in Pennsylvania opted to install 15 point of entry units to remove trichloroethylene at individual homes rather than install a distribution system connecting each home to another community's network several miles away. The long-term future cost of monitoring, maintenance, and sampling was preferable to the high one-time capital cost of installing a distribution system.

Point of entry treatment is acceptable as an available technology for complying with drinking water regulations under certain circumstances. Until recently, point of use treatment units were acceptable only for interim measures, such as a condition for obtaining a variance or exemption to avoid reasonable risk to health before full compliance can be achieved. An EPA research study is evaluating point of use units to reduce naturally occurring ground water fluoride to acceptable levels for a community of 40. It is expected that these units may be acceptable for compliance in some communities in the future.

Neither point of use nor point of entry is designated as a best available technology because of the difficulty in monitoring the reliability of treatment performance and controlling performance in a manner comparable to central treatment. All public water supplies must monitor and ensure the quality of water treatment, whether they provide central treatment or decentralized treatment through point of use/point of entry units. State approval is required for use of such units.

Both systems are available from a large number of manufacturers and most treatment technologies can be adapted to home devices. In certain situations, point of use/point of entry units can be cost-effective solutions when a very small community cannot afford central treatment for removal of a contaminant, such as an organic chemical or fluoride. For example, with state approval, several small communities (25 to 200 people) in Arizona installed home systems using activated alumina to remove fluoride. A manufacturing/engineering company on contract with one community maintains all the systems.

which evaluated water treatment filtration procedures at 48 small systems, found that, in addition to a lack of proven technology, the success or failure of a plant is often dependent on its financial status.

If a community fails to recognize the need for training and certification for operators in specific treatment processes, professional guidance and technical assistance in system selection, and adequate funding for operation and maintenance, system operation and water quality will suffer.

According to the study, an operator's technical ability and availability to perform the job are crucial to successful operation of the system. Additionally, frequency of and accessibility to training are principally responsible for improvement in water treatment performance.

Because of limited revenues, very often only part-time operators can be hired by small communities with little funding available for training and certification. Small systems normally do not have a large pool of trained engineers and scientists to deal with complex equipment or with constantly changing treatment needs. In addition, the small system might have difficulty attracting skilled staff because of economic constraints.

The ORD is investigating the utility of a telemetry system in which the package plant treatment system can be remotely monitored and operated. This approach, called a Supervisory Control and Data Acquisition system, could aid in the development of an electronic "circuit rider" that would provide service and guidance simultaneously via long distance to several systems that cannot individually afford a trained operator.

Looking Ahead

Results of the recent ORD/AWWA evaluation of package plants identified several technical issues that require further investigation for resolution.

- *As in systems of all sizes, the conflicting objectives between minimization of disinfectant by-product formation and maximization of water quality (through effective microbe reduction) are a major concern for small systems. Often, small systems may use extra chlorine just to "make sure" the water is safe, microbiologically, only to result in higher rates of disinfectant by-product formation. This in turn, may increase the risk to the community of exposure to undesirable or harmful chemicals.*

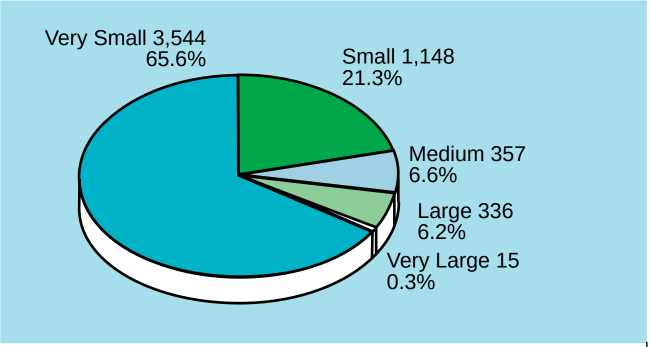
  In other cases, package plants, because of their short disinfectant contact times with water flowing through the treatment train, may not allow sufficient time for the disinfectant to be effective. This is especially true for small streams that exhibit highly variable water quality because of storms and runoff, which require a change in treatment or chemical feed rates. Thus, disinfectant by-product formation may be low, but so is disinfection efficiency.
- *In theory, the treatment technologies utilized in package plants and small systems can provide potable water and achieve reductions in* Giardia lamblia *cysts (99.9%) and viruses (99.99%), as required by the Surface Water Treatment Rule. However, there are little field data to verify this assumption.*
- *Successful operation of surface water treatment facilities may require a more sophisticated understanding of water chemistry and engineering principles than was traditionally believed necessary. Operators may need more advanced training than is typically provided. Remote monitoring and circuit rider approaches may be especially important in effectively leveraging the services of a qualified, fully capable operator.*

Research Activities

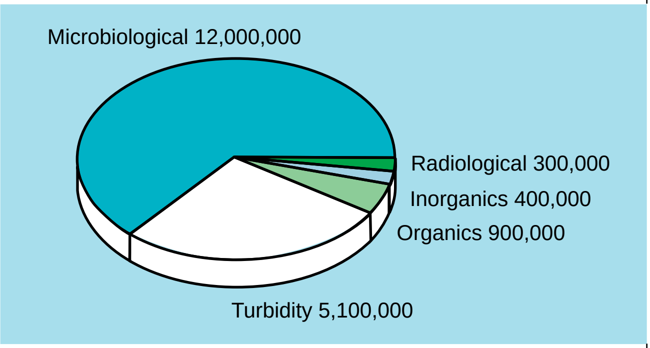
Meeting Biological Standards

Risk

Approximately 200,000 cases per year of gastroenteritis will be

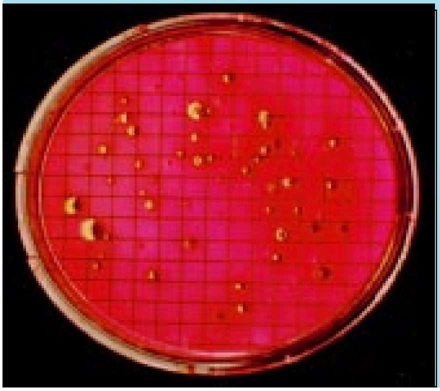


Number of systems in violation (by system size)



Population served by community systems in violation (by contaminant group)

Microorganisms called coliforms are present in water contaminated with human and animal feces. Although coliforms do not usually cause disease, their presence in drinking water indicates that disease-causing organisms may be present. If a water sample is passed through a filter, coliform bacteria present in the sample are retained and, under specific test conditions, develop into golden sheen colonies. Water samples that contain coliforms are tested further to ensure that a water supply is safe to drink.



avoided as a result of filtration and disinfection.

Small systems have the most trouble meeting EPA's standards for safe drinking water. Small systems accounted for almost 87 percent of the 5,400 systems with maximum contaminant level violations in 1991. Microbial violations accounted for the majority of these cases, putting 12 million people at risk.

Although fatal waterborne diseases are no longer a major public health threat in the U.S., there are still thousands of water-related pathogen-induced cases of illness, characterized by vomiting and diarrhea, reported annually. Fortunately, disinfection and filtration processes can eliminate the cause of such illnesses, and the Disinfection Rule will require all systems to meet new microbiological standards.

The principal immediate risk from drinking water contamination is still biological in origin with verified outbreaks of waterborne diseases caused by lack of proper treatment facilities or a breakdown in such equipment. Throughout most of recorded history, human organic waste has posed the greatest threat to safety of drinking water. Typhoid, cholera, and other waterborne infectious diseases could not be fully conquered until disinfection and filtration treatment processes were adopted.

Treatment

At a minimum, the treatment required to control microbiological contamination must include disinfection to kill disease-causing organisms. The Surface Water Treatment Rule also requires surface water systems to install some form of filtration (the process of removing suspended solids that cause turbidity) unless criteria for exemptions can be met. (Turbidity is a measure of the cloudiness of water caused by the presence of suspended matter. Turbidity can be caused by many things, including the presence of microorganisms, which can interfere with disinfection effectiveness.) These treatment technologies and standards for microbes, coliforms, and a requirement that all systems be operated by qualified operators, expand control of disease-causing microbes.

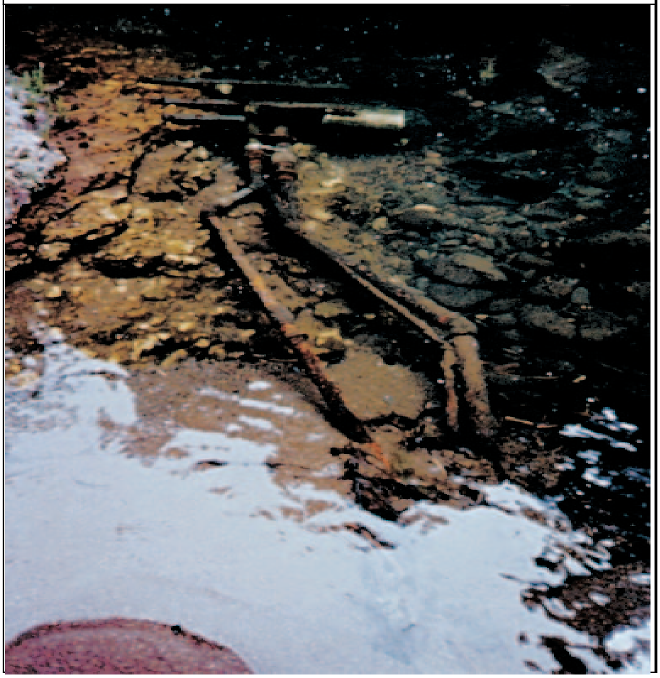
Concern has recently mounted over the ability of certain pathogenic protozoan (*Cryptosporidium*) cysts to survive treatment processes and, thus, enter the distribution system. Researchers are designing and testing filtration techniques to physically remove the cysts. Slow sand, diatomaceous earth, coagulation/rapid sand filtration, bag filtration, and membrane processes are being studied.

Research

Many small communities across the nation are seeking solutions to financing basic drinking water treatment. Two small communities in West Virginia, like thousands of other very small towns across the country with central systems (at least 15 service connections serving 25 people) distribute water from the only available source in the area. One town delivers untreated water from a cave; the other delivers minimally treated water from a collapsed mine shaft. Both sources are from unprotected aquifers. *Escherichia coli*, a bacterium indicating fecal contamination, and other microbiological contaminants were detected in both source waters

A community drinking water supply, serving about 25 homes, flowed to this tank for treatment by chlorination and aeration. Due to regulatory requirements of the SDWA, as amended, this jerry-rigged system was no longer adequate to insure a safe water supply and, thus, was recently replaced by an ultrafiltration package plant.

Example of a small community "homemade" system that provides no adequate assurance that drinking water is safe. This drinking water supply intake structure is placed in a stream bed, surrounded by mud, moss, gravel and water.



Precast manholes placed in the left side of the stream serve as drinking water intake structures for a very small community supply. Water is distributed directly to customers via the overhead hose attached to poles.

New ultrafiltration membrane package plant located by Lake Havasu.

and in one of the distribution systems.

The Chemehuevi Indian Tribe of Lake Havasu, California, distributes water from that lake to 400 people. Although raw water quality is generally good, because of intense recreational use in the summer, compliance with the Surface Water Treatment Rule is doubtful.

A sportsman camp in Lakeville, Maine, serves five cabins and a transient population of approximately 30 people daily throughout the hunting and fishing seasons. The water supply from the lake is adversely affected by erosion from clear-cut logging within its watershed. Soil and silt buildup and significant algae growth have already damaged nearby lakes, rendering them incapable of sustaining wildlife.

Disinfection is a basic requirement for each of these systems. Filtration to remove suspended solids also is a requirement for the surface water source. The ORD is working with these communities to conduct research on package plant systems to see if they are capable of meeting regulatory requirements for microbiological contamination under different water source and geographic conditions.

Ultrafiltration membrane package plants are installed in two of these community central systems to provide filtration plus disinfection. Data from monthly sampling of microbiological contaminants will determine the plants' capabilities to perform throughout changes in seasonal weather and raw water quality. Other analyses will be done throughout the system for disinfection by-products and toxic chemicals.

Meeting Organic Chemical Standards

Risk

Approximately 30 cancer deaths per year will be avoided if all water supplies lower vinyl chloride concentrations below 0.002 mg/L.

Approximately 72 cancer deaths per year will be avoided if all water supplies lower ethylene dibromide concentrations below 0.00005 mg/L.

While microbiological contamination primarily produces infectious diseases, chemical pollutants can contribute to chronic toxicity or cancer. Drinking water sources can be selected that are free of significant microbiological contaminants or protected from potentially harmful contaminants of human origin, but these same waters are vulnerable to a variety of chemicals usually related to pollution discharge or treatment. Ground water in the vicinity of improperly designed waste disposal sites often has been found to be heavily contaminated by migrating toxic chemicals.

Many synthetic organic chemicals, compounds that contain carbon, have been detected in water supplies in the U.S. Some of these, such as the solvent trichloroethylene, a carcinogen (an agent that can incite malignant tumor growth), are volatile. They easily become gases and can be inhaled in showers or baths or while washing dishes. They can also be absorbed through the skin.

More than 60,000 toxic chemicals are now being used by various segments of industry and agriculture. These substances range from industrial solvents and pesticides to cleaning preparations and degreasers. When used or discarded improperly, these chemicals pollute ground and surface waters used as sources of drinking water.

Technology and operating procedures are available to prevent release of many contaminants or control them in drinking water. However, costs can be substantial, especially for small systems, because they cannot benefit from economies of scale.

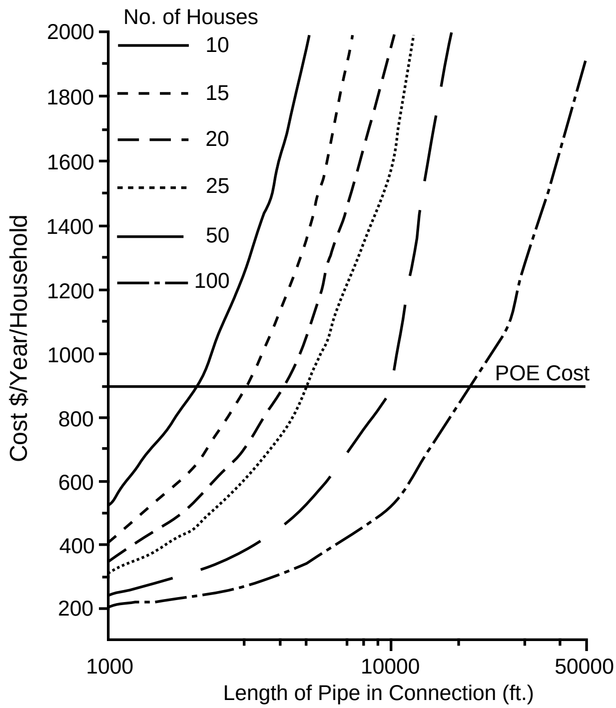
Treatment

The technologies most suitable for organic contaminant removal in small systems are granular activated carbon and aeration. The carbon process has been designated as the best available technology for synthetic organic chemical removal, and packed column aeration, as best for volatile organic chemicals. The graular activated process uses carbon that has been treated to make it extremely porous so that it can remove organic contaminants through adsorption.

Aeration, also known as air stripping, mixes air with water to volatilize contaminants. The contaminants are either released directly to the atmosphere or are treated and then released. Aeration is used to remove volatile chemicals.

Research

Organics control has been a focus of drinking water research for more than twenty years. The pioneering work contributed by ORD to this field has provided new technologies and methodologies for the standard-setting process, benefiting not only small communities but the entire drinking water community.



Cost of Point of Entry Units vs. Cost of Connecting to a Central System.

Recent studies have been comparing cost and performance of small systems (point of entry and centralized treatment technology) for removal of organic contaminants. Whole house, point of entry treatment units may provide an attractive alternative to centralized treatment technology, since costs for installing a new distribution system with central treatment or connecting to a distant water supply may be prohibitive. Conversely, with distribution systems in place, point of entry is not likely to be a viable alternative, except for the smallest utility, one that is unable financially to build a new central treatment plant, or a community with multiple source waters contaminating only a portion of the distribution system.

Various Superfund sites as well as states have been employing point of entry systems for several years in remediation programs. The predominant contaminants being removed in point of entry applications are chlorinated solvents, petroleum products, aldicarb, ethylene dibromide, and radon. Treatment technologies such as granular activated carbon, aeration, reverse osmosis, ion exchange and ozone/ultraviolet light have been widely adapted to treating water for the entire house. The removal efficiencies provided by these various systems range between 86 and 99+ percent.

Cost depends on system capacity and type of contaminants being removed. For organic chemical contamination in the water supply of a small community, granular activated carbon treatment is needed. The cost-effectiveness of a central system is in part a function of the number of households involved, total length of pipe and pumping required for connections, size and economics of the existing central plant, and additional treatment required by the central plant.

The figure above shows annual household costs of point of entry systems and those of central water supply as a function of the total length of pipe and components required for connection of the specific number of homes involved. The cost trade-offs indicate that if the average length of new distribution components required for connection to central supply per house are significantly greater than 200 feet, then point of entry may be a cost-effective alternative.

Meeting Disinfection By-Product Standards

Risk

Millions of people may be exposed to trihalomethanes in their drinking water at levels above 0.10 mg/L, resulting in approximately 50 cancer deaths annually.

A wide variety of chemicals are added to drinking water to remove various contaminants. Among them are alum, iron salts, chlorine and other oxidizing agents, all of which may leave residues or potentially hazardous by-products in the finished water. In fact, the most common source of synthetic organic chemicals in treated drinking water is the interaction of chlorine or other disinfectants with the naturally occurring particles found in the water.

Chlorine, the major disinfectant used in treatment plants to purify water supplies, can undergo complex chemical reactions when mixed with contaminated water. In the 1970s, scientists at EPA discovered that chlorine can react with natural and man-made chemicals in water to create by-products known as trihalomethanes. At least one of these by-products, chloroform, is carcinogenic in animals. Other disinfectants also have been found to generate undesirable by-products. The establishment of a maximum contaminant level for total trihalomethanes (chloroform, bromoform, bromodichloromethane, and dibromochloromethane) will control these disinfection by-products. Future regulation of compounds such as haloacetic acids will control additional disinfection by-products.

Treatment

In general, disinfection by-products are difficult and costly to remove from drinking water once they have been formed. It is better to remove the natural organic matter prior to disinfectant addition.

From an economic standpoint, alternative disinfectants should be no more expensive than chlorine. Unfortunately, since no single existing alternative disinfectant, such as ozone, chlorine dioxide, chloramines and ultraviolet radiation, can satisfy all requirements (effective, inexpensive, and can provide a disinfectant residual in the distribution system to prevent regrowth of microorganisms), a combination of alternative disinfectants is needed. Though such a strategy can be used to reduce trihalomethanes and total halogenated organic by-product levels, the combined use of these disinfectants will produce other disinfectant by-products.

Several strategies for minimizing harmful chlorination by-products are used by small systems:

1) Reduce the concentration of organic materials before adding chlorine. Water clarification techniques, such as coagulation, sedimentation, and filtration, can effectively remove many organic materials. Activated carbon may be used to remove organic materials at higher concentrations or those not removed by other techniques.

2) Reevaluate the amount of chlorine used. The same degree of disinfection may be possible with lower dosages.

3) Change the point where chlorine is added. If chlorine is presently added before treatment, instead it can be added after filtration, or after chemical treatment.

4) Use alternative disinfection methods. Ozonation and ultraviolet radiation, the alternative methods most practical for small systems, cannot be used as disinfectants by themselves. Both require a secondary disinfectant (usually chlorine) to maintain a residual in the distribution system.

Research

Research activities include studies on the maintenance of microbial quality of treated drinking water while minimizing the formation of disinfection by-products. Any changes that are made in drinking water treatment must be made in such a way that the microbial safety of drinking water is maintained. Research studies are focusing on the use of disinfectants other than chlorine and removal of precursor material by enhanced conventional treatment, granular activated carbon, and membranes for controlling disinfection by-products.

In Jefferson Parish, Louisiana, and Evansville, Indiana, work is in progress that can be applied to small systems. Mutagenicity data are being collected together with physical and chemical performance data to characterize the operating parameters for a series of treatment processes. A pilot column system will be operated to assess seasonal variations with an overall objective of comparing the effects of ozonation and various filter media in reducing ozone by-products and stabilizing water.

Other field work focuses on an integrated ozone-bioreactor system with the objective of chemically/microbiologically transforming precursors to less reactive and less problematic by-products. Other investigations focus on the use of chlorine dioxide in conjunction with a reducing agent to eliminate the metabolites, chlorite and chlorate, while controlling disinfection by-products. Membrane treatment research is evaluating the potential role of nanofiltration and reverse osmosis in removing by-product precursors from drinking water.

Meeting Inorganic Contaminant Standards

Risk

Many potential drinking water contaminants are of natural origin. There may be inorganic contaminants, such as common salts, or trace toxic substances like radium and radon. Nitrates, common in agricultural areas, can cause a disorder in infants ("blue baby" syndrome) that affects the ability of the bloodstream to carry oxygen. These health concerns are generally associated with failure to protect original water sources.

Some other inorganic contaminants are from localized geologic deposits of arsenic or selenium. Arsenic occurs naturally as an impurity in various minerals and in the ores of certain commercially mined metals. If untreated, arsenic exposure can cause liver and kidney damage.

Another natural contaminant controllable with modern technology is fluoride. Many communities add it to their drinking water in regulated amounts to improve dental health. However, excessive exposure to this inorganic chemical, which is the seventeenth most abundant substance in the earth's crust, can cause skeletal damage, as well as a brownish discoloration of teeth.

Treatment

Inorganic contaminants presently regulated under the Safe Drinking Water Act include many metals, such as arsenic, barium, cadmium, copper, lead, mercury, and nickel; other elements, such as asbestos and fluoride; and radionuclides. Conventional treatment, coagulation/filtration (initial treatment that converts nonsettleable to settleable particles), can be used to remove some inorganics. Additional technologies focus on specific contaminants.

Separation processes, reverse osmosis and electrodialysis, use a semipermeable membrane that permits only water, and not dissolved ions (atoms that have an electrical charge because they have gained or lost electrons), such as sodium and chloride, to pass through its pores. With reverse osmosis, contaminated water is subjected to a high pressure that forces pure water through the membrane, leaving most contaminants behind in a brine solution. The electrodialysis process employs electrical current to attract ions to one side of a treatment chamber. This process is effective in removing fluoride and nitrate, and can also remove barium, cadmium, selenium, radium, and other inorganics.

Ion exchange units can be used to remove many ionic (charged) substances from water. Ion exchange works by exchanging charged ions in the water for ions of similar charge on an exchange medium, usually a synthetic resin. In cation (a positively charged ion) exchange, the ions most often displaced from the resin are sodium ions. For anion (a negatively charged ion) exchange, the ion exchanged is usually chloride.

Research

Arsenic Removal

Water supply for the small rural community of San Ysidro, New Mexico, exceeded federal drinking water standards for both arsenic and fluoride. This community with 200 residents and 80 homes receives water of poor quality from ground water sources and has difficulty in providing central treatment. The water supply contains naturally occurring arsenic, fluoride, and a high level of total dissolved solids.

Researchers embarked upon a two-year study in 1988 to help the community achieve compliance and evaluate removal efficiency, cost, and management effectiveness. An initial nine-month research study with the Mobile Drinking Water Treatment Research Facility determined that the most cost-effective means of removing arsenic and fluoride from the water would be with home treatment point of use reverse osmosis units.

The eighty under-the-sink units installed in homes lowered levels of arsenic, fluoride, total dissolved solids, chloride, iron, and manganese to well below the federal standards. The cost to the customer for point of use treatment was less than half the estimated cost of proposed central treatment. To assist customer responsiveness to new treatment units, special ordinances were issued by the utility to address customer and water utility responsibilities and liability issues, and to require that the unit be installed in homes obtaining water from the utility.

To assist small communities with water supplies that exceed the maximum contaminant levels for arsenic, ORD conducted a demonstration project in four homes in Alaska and Oregon to evaluate point of use systems. These homes were supplied by private wells with water containing naturally occurring arsenic in concentrations ranging from 0.1 to 1.0 mg/L. The current standard for arsenic is 0.05 mg/L.

The pilot systems consisted of an activated alumina tank, an anion exchange tank, and a reverse osmosis system. Both point of use and point of entry systems were used. Results showed that all three treatment techniques effectively lowered arsenic concentrations in water. The ion exchange units were able to treat water containing as much as 1.16 mg arsenic/L. Additional research is needed to verify the results from the earlier study and to further define the cost and performance characteristics of these units.

Nitrate Removal

An extensive study was sponsored by ORD in 1985 in Glendale, Arizona, where 10 of 31 drinking water wells had been shut down due to excessive nitrates. The water supply, containing 18 to 25 mg/L of nitrate, was reduced to 7 mg/L in a 1-million-gallon per day plant, well below the existing maximum contaminant level of 10 mg/L.

This project (using the Mobile Drinking Water Treatment Research Facility for initial work) tested the feasibility and provided cost data for three nitrate removal technologies: reverse osmosis, electrodialysis, and ion exchange. Comparative costs for producing 1,000 gallons of treated water in the 1-million gallon per day plant were 30 cents for ion exchange, 85 cents for electrodialysis, and one dollar for reverse osmosis.

To obtain detailed information on design, operation, performance, and cost for removing nitrate by ion exchange, ORD sponsored a two and a half year study at a 1-million gallon per day plant in McFarland, California, in 1985. The plant treats close to 700 gallons of ground water per minute. Data showed that the facility reduced nitrate levels to well below the maximum contaminant level of 10 mg/L. Researchers also found that if the well was continuously pumped, the need for nitrate treatment decreased. Maximum automation was used successfully with minimum staffing, which is typical for a small water system operation. Additional research is needed to verify the concepts established during this study and should focus on alternative brine disposal techniques, as well as the concept of operating small treatment plants on an automated basis.

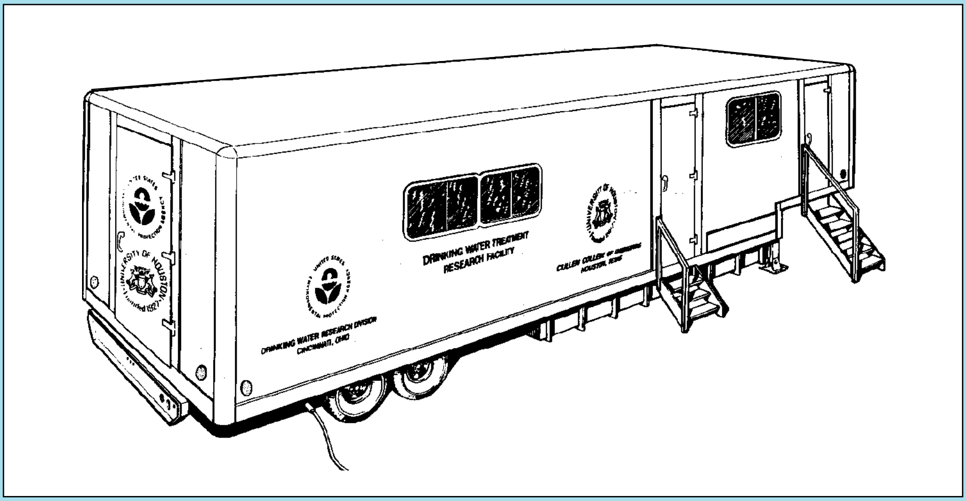
Meeting Radionuclide Standards

Risk

Radionuclides, which are known human carcinogens, exist in water supplies serving as many as 100 million people.

Radionuclides found in drinking water are members of three radioactive series, uranium, thorium, and actinium and include the naturally occurring elements radium, uranium, and the radioactive gas, radon. These radionuclides are found in drinking water supplies throughout the U.S., but certain geographic areas have particularly high levels.

Different types of ionizing radiation emitted by these contaminants may cause different levels of biological damage. Radium, when ingested, concentrates in bone and can cause cancers. Ingested uranium can cause cancers in bone and can have a toxic effect on kidneys.



EPA Mobile Drinking Water Treatment Research Facility

For over a decade, EPA's Risk Reduction Engineering Laboratory has sponsored the operation of a transportable, reusable, pilot-plant facility for inorganic contaminant removal. This pilot plant is particularly applicable to the diverse inorganic contamination problems in small communities. The plant is housed in a 10- x 40-ft. trailer that can be transported to a site to study treatment technologies applicable to a given contaminant removal problem. An estimated several thousand public water supplies in small communities in the U.S. contain inorganics that can be removed by advanced water treatment processes, such as packed beds of activated alumina, ion exchange resins, or by separation using reverse osmosis or electrodialysis. Where reliable design criteria and economical operating procedures are not available for the selection, cost-effective application, and safe operation of these processes, the mobile facility, built and operated by the University of Houston, can be transported to a site for water treatment process research and analysis.

Radon, a colorless, odorless, tasteless gas, poses unique problems. The gas, a decay product of uranium deposits, enters homes dissolved in drinking water; however, when the water is heated or agitated in a shower or washing machine, it becomes a breathable drinking water contaminant that may, in the opinion of scientists, greatly increase the risk of lung cancer. Removal of radon-222, radium-226 and -228 and uranium, all of which are carcinogenic, are in the proposal stage for regulation by the Safe Drinking Water Act at 300 pCi/L (picocuries per liter), 20 pCi/L, and 20 µg/L (micrograms per liter), respectively. Picocuries per liter is a measure of the concentration of a radioactive substance. A level of 1 pCi/L means that approximately two atoms of the radionuclide are disintegrating per minute in every liter of water.

Treatment

Today's treatment techniques also are effective against radionuclides. Reverse osmosis is effective for treating several radioactive contaminants in drinking water. Ion exchange can be used to remove radium and uranium. Radon removal requires use of granular activated carbon or aeration techniques. Each of the treatment processes for removing radionuclides from drinking water generates waste that must be handled and disposed with care.

Research

Uranium Removal

Uranium-contaminated drinking water is a common problem, particularly in the western U.S. Approximately 100 to 200 community water supplies treat their water to reduce uranium levels to concentrations that meet federal regulations.

Removal of uranium from ground water supplies in New Mexico and Colorado was demonstrated in studies by ORD to both reduce levels that were 20 times the proposed maximum contaminant level and to determine operating characteristics, costs and uranium treatment waste disposal options. Four ion exchange columns, housing three different types of resins, were pilot-tested in New Mexico and a full-scale ion exchange system was evaluated in Colorado.

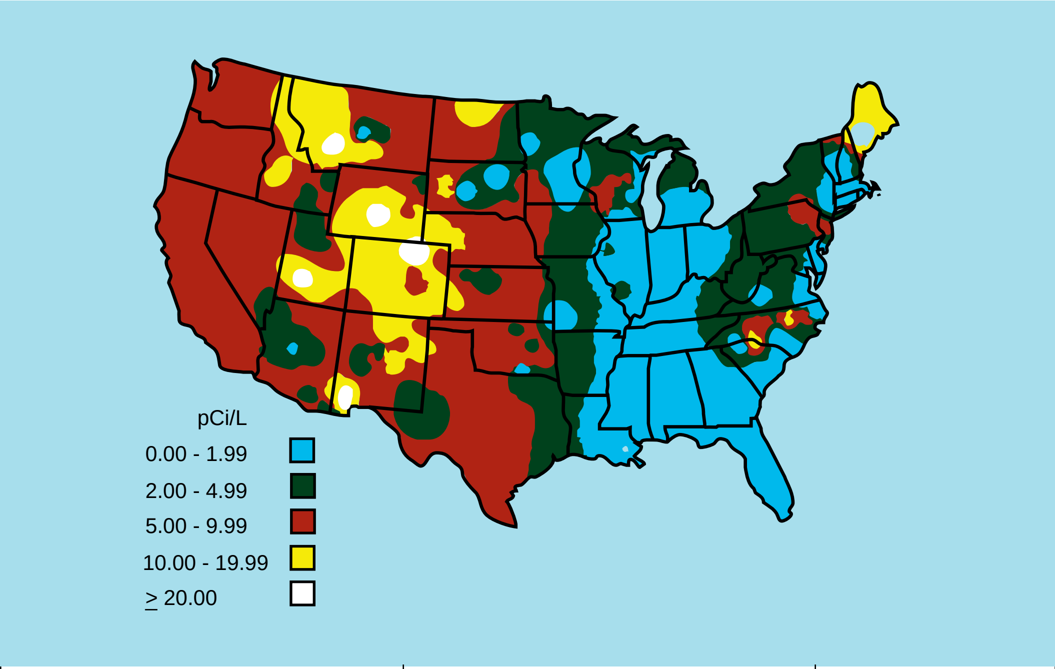
Results showed that anion exchange can remove more than 99 percent of the uranium present in raw water at reasonable cost. Disposal of uranium-laden wastewater was a complex task because of the sophisticated sample analyses required. Operation and maintenance costs for such removal systems will be high. The removal efficiency of these units is very much a function of the source water matrix. Additional research is needed to define the removal characteristics of these unit processes as a function of source water characteristics. The general cost and performance of these unit processes also must be verified.

Radon Removal

Aeration and granular activated carbon treatment to remove radon have been demonstrated extensively as highly effective (greater than 90 percent removal) and reliable. ORD participated in a study to analyze a large body of performance data to determine the effectiveness of home treatment units to remove radon from drinking water. Point of entry granular activated carbon units were installed at 122 sites in 12 states by Lowry et al. to treat ground water supplies with varying quality characteristics.

The treatment units were single vessels containing 1 to 3 cubic feet of granular activated carbon. Most units were installed downstream of an existing pressure tank and were operated under existing water pressure in the home. In general, the only maintenance required was twice-yearly replacement or washing of the sediment filter. Researchers concluded that a typical point of entry granular activated carbon unit may last a decade.

Researchers also have demonstrated that low cost/low technology aeration techniques can be applied easily in small communities to significantly lower radon concentrations in drinking water. At a 33-home trailer park in New Hampshire, removal of 60 to 87 percent was achieved with simple aeration and by retaining water in a storage holding tank for nine hours to allow for decay of radon. Better than 95 percent removal was observed by increasing retention time to 30 hours, also with aeration applied.



Average total uranium concentrations in public ground water supplies.

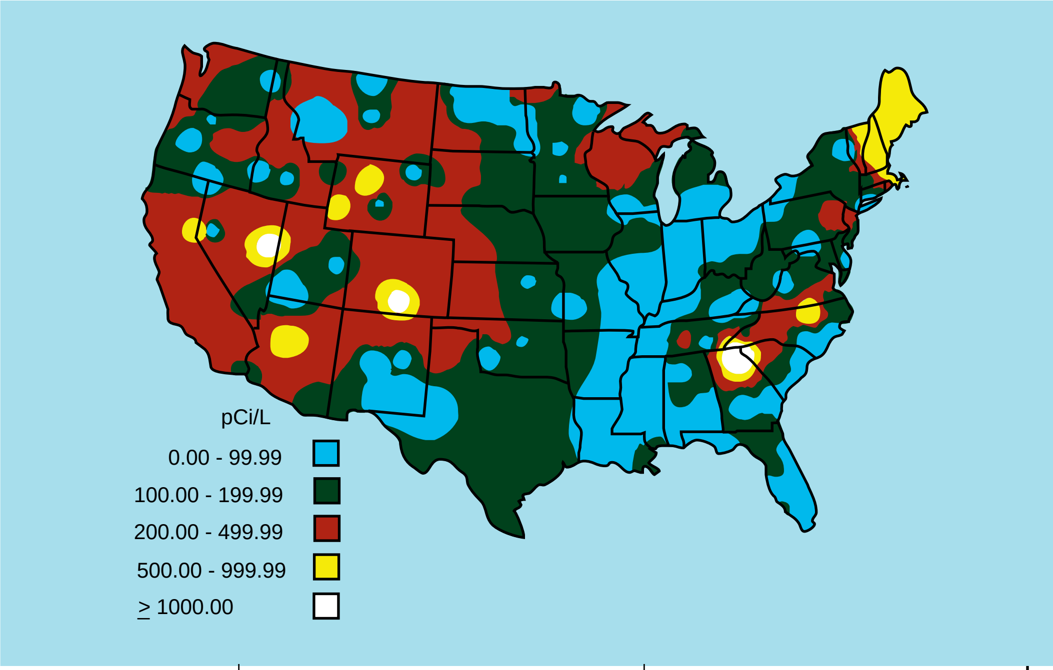
To compare three types of point of entry treatment systems for removal of radon, researchers evaluated granular activated carbon (with and without ion exchange pretreatment) and two types of aeration devices, diffused bubble and bubble plate. The granular activated carbon unit proved to be the easiest to operate and maintain and the least expensive. Radon concentrations were always reduced, but not necessarily at the same rates. Waste from the system may require special handling and disposal. The aeration systems were very efficient in removing radon; however, they were more susceptible to operational problems. Comparative studies are needed to further define the most efficient type of unit process for proposed maximum contaminant levels and under various source water conditions.

Radium Removal

More than 175 cities in the Midwest deliver drinking water that contains radium in concentrations that exceed proposed federal standards. To assist small communities with compliance, ORD investigated several treatment methods to remove radium economically from drinking water.

A study in Iowa evaluated possible economical ways to remove radium from drinking water by typical iron removal plants. The study found that sorption of radium to manganese oxides could possibly be exploited to remove radium, and that filter sand was able to sorb significant concentrations of radium at typical hardness concentrations, if the sand is periodically rinsed with a dilute acid.

Researchers, over a two-year period, also evaluated a system to remove radium from ion exchange



Average radon-222 (Rn-222) concentrations in public ground water supplies.

waste at a small water treatment facility in Redhill Forest, Colorado, where raw water comes from deep wells and contains naturally occurring radium, radon and iron. The treatment system consisted of aeration to remove radon gas and carbon dioxide, chemical clarification to remove iron and manganese, and ion exchange to remove radium and reduce “hardness” or pH level. A separate system removed only radium from the regeneration water (brine) of the ion exchange process by permanently complexing it on a radium selective complexer resin. This treatment was found to be very efficient in the removal of radium from the ion exchange process wastewater.

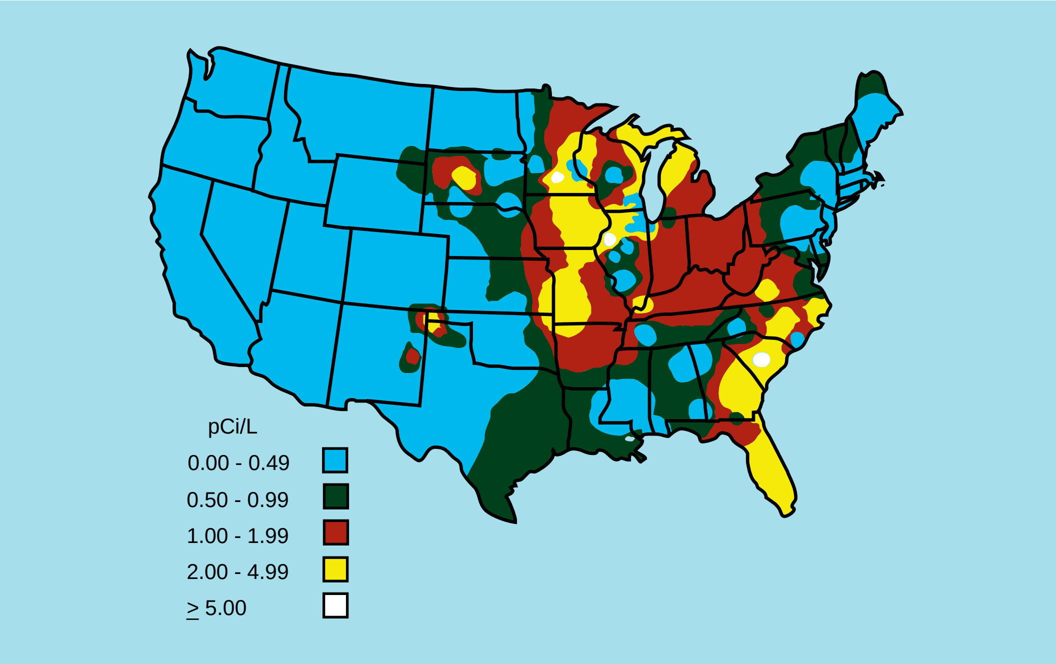
Full-scale application of radium adsorption onto MnO_2-coated filters was tested at several small public water systems in North Carolina. The filter tests showed that for hard water (pH=7.4), total radium removal was 14,200 pCi/g MnO_2 before the maximum contaminant level was exceeded. For softer water (pH=4.5), total radium removal was 5,000 pCi/g MnO_2 before the maximum contaminant level was exceeded. The filters also can remove low concentrations of cadmium, calcium, cobalt, cesium, iron, and manganese. Future work in this area is needed to define cost-effective treatment technologies for removing radium with special emphasis on residual disposal.

Meeting Corrosion By-Product Standards

Risk

Millions of people may be exposed to lead, resulting in potential risk of central and peripheral nervous system damage, particularly to infants and fetuses.

Exposure to excessive levels of lead and copper in drinking water is primarily caused by corrosion



Average radium-226 (Ra-226) concentrations in public ground water supplies.

resulting from the contact of corrosive water with these materials found throughout water distribution systems and in the plumbing of private homes. Of particular concern is the presence of lead service lines and connections, lead pipes in the home, and lead solder that is less than five years old. In 1986, EPA estimated that as many as 42 million people in the U.S. may be exposed to water lead levels in excess of 20 µg/L. In homes less than five years old that contain lead solder, it is not uncommon to find water lead levels in excess of 100 µg/L. The most cost effective way to prevent lead and copper corrosion by-products and reduce the risks posed to human health and the environment is through comprehensive corrosion reduction carried out by water suppliers.

Where lead is present in pipes and soldered connections, the lead dissolves into the water while the water is not moving, generally overnight or other times when the water supply is not used for several hours at a time. The first water that comes from the faucet after long periods of no use may have lead in it. Future use of lead pipe and lead solder has been banned. New standards for lead and copper will require treatment of water to inhibit corrosion and the leaching of lead from the distribution system.

In many areas of the U.S., homeowners and small water supply systems use water that is potentially corrosive to metallic materials (copper, lead, and zinc) in the distribution system. Corrosion can be caused by the use of minimally acidic waters (low pH or alkalinity) and concentrations of dissolved solids. Health problems can result from ingestion of corrosion by-products, aesthetic quality of the water can decline, and costs due to piping system deterioration may rise.

Corrosion has caused severe blockage in an 8-inch water main pipe. The reddish coloration is rust that has built up over time and now acts to harbor bacteria in the distribution system.

Treatment

Lead levels in drinking water are managed indirectly through corrosion controls. Lead is not typically found in source water, but rather at the consumer's tap as a result of the corrosion of the plumbing or distribution system. If tests for corrosion by-products find unacceptably high levels of lead, immediate steps should be taken to minimize consumers' exposure until a long-term corrosion control plan is implemented.

Research

To control the input of lead and copper into drinking water, the research program is determining the water chemistry and physical factors responsible for the uptake of lead and copper in drinking water; developing chemically-sound and practical treatment strategies for lead and copper control that are applicable to water systems of all sizes; determining potential adverse side effects on other materials and potential users; and demonstrating the effectiveness of different treatment processes.

To control corrosion in small systems using minimally acidic water, ORD sponsored research to derive and test a model for limestone contactor design, examine the relationship between contactor-treated water quality and metal release from pipes, and monitor the field performance of full-scale contactors. Results indicated that limestone contactors can effectively reduce the tendency of water to take up corrosion by-products from surfaces in piping systems.

Pilot studies are being conducted at the Cincinnati Lab to test the effects of different major water chemistry variables on lead pipe and other plumbing materials. Studies will determine potential inhibitors and mechanisms of lead and copper corrosion protection in actual pipe systems, and integrate this information into a predictive theory of leaching control. Basic investigations will be conducted on the equilibria of solubility and transport and the effect of pH, carbonate, ortho and polyphosphate, and temperature on fundamental chemical constants.

Other studies will focus on the extent of corrosion and remediation strategies for a range of water qualities and problems. Designs of treatment systems will be developed that require little operator attention and that provide consistent water

quality and corrosion control for small suppliers. Additional investigation will be conducted on the mechanism and control of lead leaching from brass and solder.

Summary

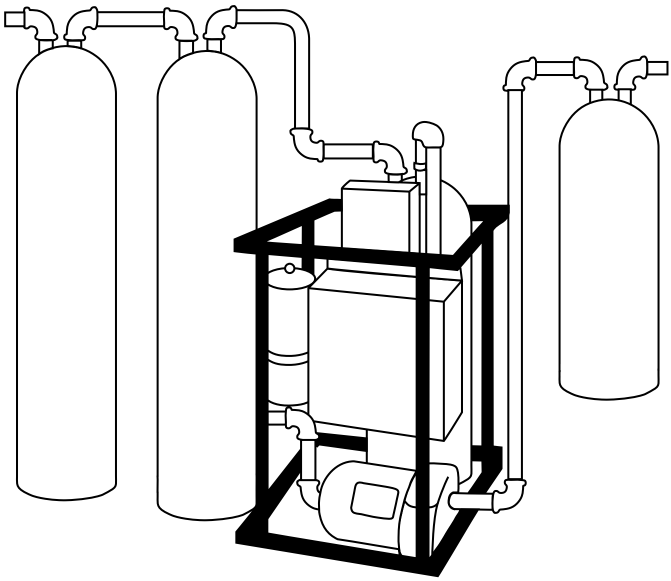
When evaluating treatment options and alternatives for small systems and private homeowners, decision-makers will have to consider the potentially very high cost for custom designed central treatment and its long-term operation and maintenance versus maintenance and monitoring of package plants or home treatment units. Package plants or point of entry units may present a cost-effective solution for small systems and individual homeowners, eliminating many of the problems small systems face when attempting to finance and operate central treatment facilities.

Currently, several states are enacting legislation to require certification of treatment units, certification of water quality for home loans, and tougher "truth in advertising" requirements for water treatment units. Several states are also making it easier to acquire funds for treatment technology installation and upgrades and for the creation of water quality districts to address the problems of small systems and rural homeowners.

The President's budget for fiscal year 1994 includes resources to help meet state and local needs in protecting the nation's drinking water. Close to six hundred million

Rust is indicative of corrosion in a small drinking water distribution system built in1935 that has not been well maintained.

A schematic of a point of entry unit for disinfection by ozone and ultraviolet light. The unit receives raw water at right, which travels through a prefilter, ozone generator, ultraviolet light, contact chamber, and polishing step (optional) to produce the finished water (outlet at left).



dollars will be invested by EPA in a Drinking Water State Revolving Fund to provide low-interest loans to communities for the repair and improvement of existing systems.

Documentation of increasing contamination of the nation's ground water is abundant. Small systems and private homeowners have been and will continue to be the most vulnerable and least capable of meeting current and future drinking water regulations. However, long-term cost-competitive alternatives are becoming available in terms of package plants and home treatment units to reduce the risk of contaminated drinking water.

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Sources of Information

Federal Funding Programs for Small Public Water Systems

Appalachian Regional Commission	(202) 673-7874
Dept. of Housing and Urban Development	(202) 708-2690
Community Development Block Grants	
Economic Development Administration	(202) 482-5113
Indian Health Service	(301) 443-1083
Rural Development Administration	(202) 720-9589
(formerly Farmer's Home Administration)	

Technical and Administrative Support for Small Public Water Systems

American Water Works Association	(800) 366-0107
National Rural Water Association	(405) 252-0629
Rural Community Assistance Program	(703) 771-8636
Rural Electrification Administration	(202) 720-9540
(private; provides some financial funding)	
Rural Information Center	(800) 633-7701
National Drinking Water Clearinghouse	(800) 624-8301
USEPA, A. W. Breidenbach Environmental Research Center,	
Risk Reduction Engineering Laboratory, Robert M. Clark	(513) 569-7201

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Phone: (513) 569-7562 FAX: (513) 569-7566

The research described in this report was funded by the U.S. Environmental Protection Agency and conducted as part of the Office of Research and Development's comprehensive long-term Research Issue Plan for Drinking Water.

This publication was prepared by Carol Grove of ORD's Center for Environmental Research Information (CERI), Cincinnati, Ohio, under the Office of Science, Planning and Regulatory Evaluation. It was prepared from information developed by Jim Goodrich and staff of the Drinking Water Research Division, Risk Reduction Engineering Laboratory (RREL), Cincinnati. Other contributors and reviewers include Robert Clark, Tom Sorg, Ben Lykins, Walter Feige, Kim Fox, and Sue Campbell, RREL - Cincinnati; Rita Shoeny, Environmental Criteria and Assessment Office - Cincinnati; Ronnie Levin, Office of Science, Planning and Regulatory Evaluation; and Peter Shanaghan, Office of Water.

Thanks to Jim Goodrich, Sue Campbell, and Ed Geldreich of RREL and Jim Walasek, Office of Water, Technical Support Division, for photographic support and to Steve Wilson, CERI, for graphics support.