Potable use of reclaimed water

Indirect potable reuse is a viable application of reclaimed water if indicated by site-specific assessments that include contaminant monitoring, health and safety testing, and system reliability evaluation.

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The National Research Council released a report in 1998 that evaluated the feasibility of augmenting drinking water supplies with highly treated reclaimed water. The report concluded that indirect potable reuse of reclaimed water (i.e., using reclaimed water to augment a potable water source before treatment) is viable and that direct potable reuse (i.e., introducing reclaimed water directly into a water distribution system) is not viable. Although recent health-related research has uncovered no adverse effects, such health data are sparse, and the methods for such research are limited. Consequently, the results cannot be extrapolated to potable reuse in general. Thus, each indirect potable reuse project should be implemented only after a thorough, project-specific assessment of health concerns and measures to mitigate them. Finally, potable reuse should only be considered in communities in which other efforts—water conservation, development of new water sources, and nonpotable reuse—cannot cost-effectively meet the communities' needs. This article describes the council's recommendations for ensuring the safety of water systems that augment raw water sources with reclaimed water.

Programs that reuse municipal wastewater to meet nonpotable urban water needs have grown in number and scope and are well established in the United States. Nonpotable reuse can augment the water supply in areas in which the growth of urbanized populations has outpaced the development of affordable new water sources. In addition, a small but increasing number of municipalities have implemented or are considering water reuse projects to augment potable water supplies with highly treated reclaimed water (see sidebar on page 42).

Treatment technology has advanced to the point that reclaimed water of very high quality can be produced from municipal wastewater. However, questions remain about the levels of treatment and testing necessary to pro-

For executive summary, see page 169.

The Rio Hondo spreading grounds in California cover about 570 acres. Water for recharge is fed to the 20 shallow basins over a period of seven days. The basins are then drained for seven days and dried for an additional severn days.

tect human health when reclaimed water is used for potable purposes. Some public health and engineering professionals object to the reuse of wastewater for potable purposes in principle. To support their objection, they cite the US Environmental Protection Agency drinking water regulations, which state ". . . priority should be given to selection of the purest source. Polluted sources should not be used unless other sources are economically unavailable."[1] Others express concern that current techniques are inadequate for detecting all microbial and chemical contaminants of health significance that may be present in reclaimed water. State regulations offer conflicting guidance on whether potable reuse is acceptable and, when it is acceptable, what safeguards should be in place.

In response to a need to assess the viability, health effects, and safety of potable reuse, the National Research Council (NRC) appointed a committee with expertise in environmental and chemical engineering, microbiology, risk assessment, epidemiology, and toxicology to evaluate issues associated with potable reuse of reclaimed wastewater. The NRC published the committee's findings in 1998. This article summarizes the key conclusions and recommendations of the committee's report, titled *Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies With Reclaimed Water.*[2] In particular, this article presents recommendations to help communities considering indirect potable reuse make decisions that will protect the populations they serve.

Direct use of reclaimed water, without the added protection provided by storage in the environment, is currently not a viable option for public water supplies.

Report focuses on planned indirect potable reuse

The report focused on planned indirect potable reuse of municipal wastewater—i.e., the purposeful augmentation of a potable water supply source (generally a reservoir or aquifer) with highly treated reclaimed water derived from treated municipal wastewater. In indirect potable reuse systems, the mix of reclaimed and "natural" source water receives additional treatment at a conventional treatment facility before distribution. (In contrast, direct potable reuse involves the immediate addition of reclaimed water to the potable water distribution system. The committee specifically discourages this practice.) The committee addressed issues related to reclaimed water treatment, microbial and chemical constituents of concern, monitoring, health effects, and research. As its starting point, the committee used the findings of a 1982 NRC report titled *Quality Criteria for Water Reuse.*[3]

Most of the issues raised in the committee's report are also important for any drinking water drawn from a source that receives incidental or unplanned upstream wastewater discharges. Many communities use water sources that include a significant wastewater component. More than two dozen major US water utilities use water from rivers that receive wastewater discharges amounting to more than 50 percent of stream flow during low-flow conditions. It is sometimes said that these cities practice "unplanned" potable reuse.

Although such water meets current drinking water regulations, most of the concerns about planned, indirect potable reuse raised in the NRC report apply equally well to these conventional water systems. Pollution of these existing sources does not give carte blanche for adding reclaimed water to these water supplies, nor does it justify the continued use of these polluted sources. But the judgments made about the risk associated with reuse should recognize the real

US Examples of Indirect Potable Reuse Systems

Los Angeles County, Calif.

Since 1962, the Whittier Narrows Water Reclamation Plant in Los Angeles County has been using treated wastewater, along with surface water and stormwater, to recharge groundwater in the Montebello Forebay. The wastewater undergoes secondary treatment and then granular-media filtration and chlorination–dechlorination before it is discharged in spreading areas that recharge the groundwater. The treated wastewater then percolates through 3–12 m (10–40 ft) of soil before reaching the groundwater, which serves as the potable water supply for some area residents.

El Paso, Texas

The Fred Hervey Water Reclamation Plant, operating since 1985, recycles wastewater from El Paso back to the Hueco Bolson aquifer to prevent saltwater intrusion and aquifer depletion. The aquifer serves as the water supply source for El Paso and Juarez, Mexico. The wastewater undergoes advanced treatment before underground injection through 10 wells to the deep water table (107 m [350 ft] belowground).

Fountain Valley, Calif.

Since 1976, Orange County Water District in Fountain Valley has been injecting highly treated municipal wastewater into water supply aquifers. Treated effluent from the County Sanitation District of Orange County wastewater treatment facility is transported to Water Factory 21, an advanced wastewater treatment facility, in which it undergoes advanced treatment. The treated water is then blended two-to-one with deep well water from a pristine aquifer, chlorinated in a blending reservoir, and injected into the ground. On average, more than 50 percent of the injected water flows inland to the potable water supply. The rest creates a barrier that prevents saltwater intrusion.

risks associated with the existing water supplies as well as the lesser risks of other, more protected, water supplies the community might use. However, because the NRC study focused on planned indirect potable reuse, the report does not directly address the broader issues concerning contamination of water supplies with wastewater discharges.

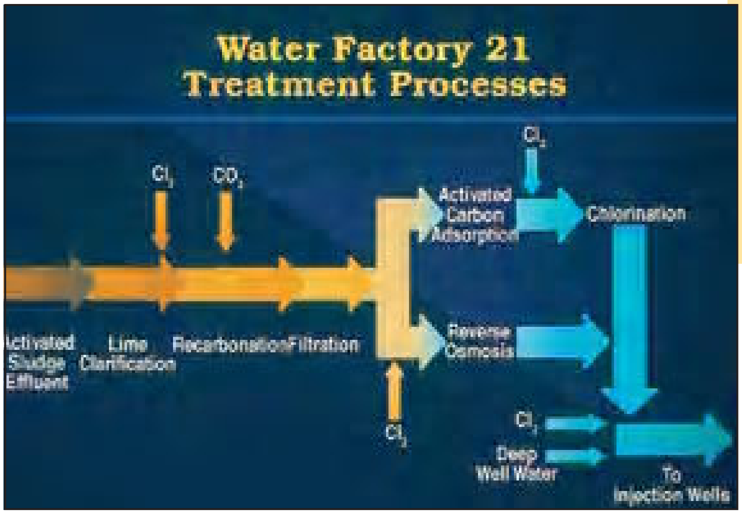
Indirect potable reuse is viable; direct potable reuse is not

The report's general conclusion is that ". . . planned indirect potable reuse is a viable application of reclaimed water—but only when there is a careful, thorough, project-specific assessment that includes contaminant monitoring, health and safety testing, and system reliability evaluation." Direct use of reclaimed water, without the added protection provided by storage in the environment, is currently not a viable option for public water supplies.

When the report was released, one statement in the executive summary attracted attention in the popular press. Because it was taken out of context, it requires additional clarification. After the general conclusion about indirect potable reuse being a viable option, the report states, ". . . indirect potable reuse is an option of last resort. It should be adopted only if other measures—including other water sources, nonpotable reuse, and water conservation—have been evaluated and rejected as technically or economically infeasible."

This statement was included for two reasons. First, seeking the most protected source for drinking water supplies is an important and long-standing principle. Because municipal wastewater can hardly be considered a protected supply, it is, in this sense, a water source of last resort. Thus, the level of treatment and other barriers to cross-contamination placed between that supply and the finished drinking water itself are critical concerns. Second, communities should avoid the temptation to use potable reuse to dispose of wastewater. Potable reuse should be considered only in communities in which other efforts to balance demand and supply of water, such as water conservation, development of new water sources, and nonpotable reuse, cannot cost-effectively meet the community's needs. Nonetheless, indirect potable reuse, when used with appropriate precautions, can be an acceptable alternative for communities to consider.

Reuse requirements should exceed those for drinking water and wastewater treatment. The report also concluded that requirements for planned indirect potable reuse should exceed those that normally apply to drinking water and wastewater treatment facilities. Although existing indirect potable reuse projects generally produce reclaimed water that meets or exceeds the quality of raw water those systems would otherwise use, the current drinking water regulations were not designed to address all of the issues raised by potable reuse. Whereas these regulations must clearly be met, they cannot be relied on as an adequate standard of safety. The drinking water



Water Factory 21 treats wastewater (left) from Orange County Sanitation District by reverse osmosis (below). More than half the injected wastewater flows inland to the potable water supply.

standards developed during the past decades were designed for water obtained from conventional, relatively uncontaminated sources of freshwater—not for reclaimed water.

Health risk data are sparse. A third conclusion is that information is lacking regarding health risks posed by some microbial pathogens and chemical constituents in reclaimed water. Health-related research generated to date includes both animal testing and epidemiological studies, and this work has identified no obvious adverse health effects associated with indirect potable reuse in the specific projects examined (Table 1).

However, the data from these studies are sparse. This sparseness and the limited nature of the toxicological and epidemiological techniques used prevent extrapolation of these results to potable reuse projects in general. As a result, each individual potable reuse project will need to perform extensive testing to ensure that adequate public health protection is provided.

Because drinking water standards do not address all of the concerns in potable reuse systems and because of the limited data on health risks of reclaimed water, communities considering potable reuse are advised to "fully evaluate the potential public health impacts from the microbial pathogens and chemical contaminants found or likely to be found in treated wastewater through special microbiological, chemical, toxicological, and epidemiological studies, monitoring programs, risk assessments, and system reliability assessments."

Once this evaluation is done, public health can be protected in two ways: (1) by providing treatment that is increasingly effective and more reliable and (2) through monitoring that is more comprehensive in scope and frequency. Both components are required in any potable reuse project, but generally a balance must be achieved between them. Projects with less conservative treatment should incorporate more comprehensive monitoring, and vice versa. The remainder of this article describes approaches to monitoring and treatment that the NRC report recommends to ensure indirect potable reuse systems provide water that is acceptable to the public.

More than two dozen major US water utilities use water from rivers that receive wastewater discharges amounting to more than 50 percent of stream flow during low-flow conditions.

Chemical constituents must be controlled

Wastewater contains various types of contaminants. Municipal wastewater contains various types of chemical contaminants. These include naturally occurring inorganic chemicals and minerals, generally at concentrations > 1 mg/L; chemicals of anthropogenic origin, generally at concentrations < 1 mg/L; and chemicals that are added or generated during water and wastewater treatment and distribution processes. Wastewater may also contain unidentified or unknown chemical constituents, such as proprietary industrial chemicals and their metabolites, unidentified halogenated compounds, and pharmaceuticals. Any of these chemicals might pose some long-term risks, and the risks may change from one location and time to the next. The ability to understand those risks is greatest for minerals and trace organics, less for identified organic compounds and disinfection byproducts, and minimal for the unidentified mix that comprises most of the organics in water.

The ability of advanced wastewater treatment processes to remove many trace chemical contaminants is well established. Most potable reuse studies have shown that advanced wastewater treatment can produce water that meets the standards for specific chemical contaminants identified in the US drinking water standards.[4–8] Meeting this requirement is necessary but not sufficient for establishing that water produced from advanced wastewater treatment is acceptable. Although the potential exists for a water reclamation plant to fail, monitoring at the water treatment plant would likely identify elevated concentrations of a regulated contaminant. Further, for most contaminants, at the low concentrations likely to be present, risk is associated with lifetime contamination rather than with acute toxicity.

For many compounds in wastewater, the absence of reliable detection methods or techniques for quantifying concentrations in reclaimed water creates uncertainty regarding health risks.

Many identifiable and quantifiable contaminants are regulated in existing pretreatment regulations. Communities considering potable reuse should upgrade those programs to address all identifiable and quantifiable contaminants of concern in their wastewater. Then, there is a small probability that a spike of a regulated contaminant would pass undetected through a reclaimed water treatment plant, environmental buffer, and water treatment plant. Because there is a small likelihood that such a contaminant spike would acutely affect consumers, the risk associated with this type of event is also small. As a result, identifiable and quantifiable contaminants in wastewater pose a manageable risk with respect to their presence in finished potable water. Communities considering potable reuse should implement more rigorous pretreatment programs to control these contaminants, but the implementation should be within reach of current technology.

Lack of reliable detection methods creates uncertainty. For many compounds in wastewater, the absence of reliable detection methods or techniques for quantifying concentrations in reclaimed water creates uncertainty regarding health risks. Because it is impossible to identify the complete mix of compounds present in water, such uncertainty will remain a perpetual issue in evaluations of indirect potable reuse. This uncertainty can be reduced through toxicological testing, which is discussed later in this article. Another approach is to establish a quantifiable limit for a surrogate or composite parameter that provides information on the concentration or behavior of unknown or suspected health-significant compounds.

Total organic carbon (TOC) is a surrogate parameter. TOC, which is widely used as a measure of treatment process effectiveness, is one such surrogate parameter. Some would argue that TOC provides negligible value for indicating the potential hazard associated with consumption of water. This assertion is probably justified because TOC removal is of limited value from a strict risk assessment perspective. However, removing TOC from water almost certainly reduces—though not necessarily proportionally—the concentration of potentially hazardous, unidentified organic compounds. Diluting reclaimed water has a similar effect. Either method of reducing dissolved organic carbon or TOC in the source water would reduce the exposure to hazardous, unidentified organic constituents that might be present in water. Similarly, limiting the amount of total organic halogen (TOX) that is introduced into a water supply from reclaimed water might provide a measure of safety because TOX provides a surrogate measure for several chemicals with known or suspected health effects.

Potable reuse projects should account for chemical contaminants. Potable reuse projects should use a variety of approaches to account for identifiable and unidentifiable chemical contaminants.

- Proposed potable reuse projects should include documentation of all major chemicals that enter the wastewater system from household, industrial, and agricultural sources. Special attention should be paid to chemicals that pose the greatest health concern. The discharge of undesirable chemicals to the sewer should be regulated through amendments to existing industrial pretreatment programs.
- Safe Drinking Water Act (SDWA) regulations alone cannot ensure the safety of drinking water produced from treated wastewater; however, potable reuse projects must nonetheless bring concentrations within those regulations' guidelines. Although the SDWA regulations were not written with potable reuse in mind, they constitute the current US roster of safe concentrations of important drinking water contaminants. Meeting these regulations is a "necessary but not sufficient" requirement for any potable reuse project.
- The risks posed by unidentifiable or unknown contaminants in reuse systems should be managed through a combination of reducing concentrations of general contaminant classes, such as TOC, and conducting toxicological studies of the water. Reducing the amount of organic matter to the lowest practical concentration will lessen, but not necessarily eliminate, the need for toxicological studies and monitoring. The nature of the organic carbon in the water will influence what the appropriate TOC limit should

TABLE 1 **Health-effect studies of reclaimed water**

Study Location	Type of Reclaimed Water Studied	Type of Studies	Major Findings
Windhoek, Namibia[12]	Effluent from full-scale advanced wastewater treatment plant (secondary treatment, alum addition, dissolved-air flotation, chlorination, lime treatment, sand filtration, chlorination, GAC,* and final chlorination)	Toxicological (short-term in vivo), epidemiological	No relationship was observed between drinking water source and incidence of diarrheal diseases
Los Angeles County, Calif.[4,13]	Water recovered from aquifer recharged with reclaimed water via surface spreading (secondary treatment, filtration, and chlorination–dechlorination)	Toxicological (in vitro), epidemiological	No relationship was observed between percent of reclaimed water in wells and observed mutagenicity in toxicological tests. In epidemiological studies, populations ingesting reclaimed water showed no measurable adverse health effects.
Washington, D.C.[14]	Effluent from the Potomac Estuary Experimental Water Treatment Plant (secondary treatment, aeration, coagulation, flocculation, sedimentation, predisinfection, filtration, GAC, and postdisinfection)	Toxicological (in vitro)	No significant differences were observed between toxicological properties of the reclaimed water and water from three nearby conventional water treatment plants.
Denver, Colo.[15]	Effluent from a demonstration advanced wastewater treatment plant (secondary treatment, lime treatment, recarbonation, filtration, selective ion exchange, GAC, ozonation, reverse osmosis, air-stripping, and chlorination)	Toxicological (in vitro and in vivo)	No treatment-related effects were observed in toxicological tests using organic residue concentrates for in vivo studies.
San Diego, Calif.[16]	Effluent from a pilot-scale advanced wastewater treatment plant (secondary treatment, coagulant addition, filtration, ultraviolet disinfection, reverse osmosis, air-stripping, and GAC)	Toxicological (in vitro and short-term in vivo)	Reclaimed water showed less mutagenic activity than water from the conventional drinking water source.
Tampa, Fla.[6,17]	Effluent from pilot-scale advanced wastewater treatment plant (secondary treatment, filtration, denitrification, lime treatment, recarbonation, filtration, GAC, and ozonation)	Toxicological (in vitro and in vivo)	All toxicological tests were negative except for some fetal toxicity exhibited in rats (but not mice) for the advanced wastewater treatment sample.

*GAC—granular activated carbon

be. Local regulators, integrating all of the available information concerning a specific project, should make this judgment.

- Every reuse project should have a rigorous and regularly updated monitoring system to ensure the safety of the water. This program should be updated periodically as inputs to the system change or as its results reveal areas of weakness. Pretreatment requirements, wastewater treatment processes, and monitoring requirements may need to be modified to protect public health from exposure to specific chemical constituents.

Microbial contaminants must be controlled

Little information is available on the occurrence of microbial contaminants in reclaimed water. The microbiological quality of drinking water has typically been evaluated and regulated according to bacterial indicators (total coliform bacteria) of fecal contamination. This strategy has worked effectively in controlling classic waterborne bacterial diseases such as dysentery, typhoid fever, and cholera.[9] Today, however, most US waterborne disease outbreaks—and the waterborne diseases likely to be of concern in potable reuse systems—are caused by viral and protozoan pathogens in water that meets the total coliform standards. *Giardia, Cryptosporidium,* and enteric viruses are the three types of organisms of greatest concern in the design of potable reuse systems.

Emerging pathogens may also be present in wastewater. Wastewater may also contain a number of newly recognized or emerging waterborne pathogens or potential pathogens, and their removal by treatment can only be inferred from other measures of microbial quality. Emerging infectious diseases are those whose incidence in humans has increased within the past two decades or threatens to increase soon.[10] The occurrence and health significance of many of these agents in drinking water are unknown. Examples of emerging waterborne pathogens include Norwalk virus, calicivirus, astrovirus, the bacterium *Helicobacter pylori,* and the protozoa *Cyclospora cayetanensis* and microsporidia. Two types of aquatic microorganisms, aeromonads and cyanobacteria, are emerging pathogens which, although not infectious, may be of concern for potable reuse systems. This is because their densities in water and their production of toxins could be influenced by wastewater nutrients.

Steps should be taken to reduce health risks posed by pathogens. Potable reuse systems should take steps to reduce existing and potential health risks posed by microbial pathogens and to increase the knowledge base about how these pathogens are affected by various levels of treatment.

• Potable reuse systems should continue to use a combination of advanced physical treatment processes and strong chemical disinfectants as the principal line of defense against microbial contaminants. Some new membrane treatment processes can almost completely remove microbial pathogens of all kinds, but experience with them is not yet adequate to depend on them alone for protection against the serious risks posed by microbial pathogens. Thus, strong chemical disinfectants, such as ozone or free chlorine, should also be used, even in systems with physical barriers to microbial contamination.

• Potable reuse facilities should assess and report the effectiveness of their treatment processes in removing microbial pathogens so that industry professionals and regulators can develop operational guidelines and standards. Reuse projects should provide data on number of barriers, microbial reduction performance, treatment reliability, and variation in water quality.

Although the SDWA regulations were not written with potable reuse in mind, they constitute the current US roster of safe concentrations of important drinking water contaminants.

Health risks must be assessed

Detection methods have limitations. Any utility considering a potable reuse project should prepare the best possible estimates of microbial and chemical risks of using reclaimed water compared with using other available water sources. Current microbial methods to detect bacterial, viral, and protozoan microorganisms all have limitations when used to detect pathogens in reclaimed water. Bacterial detection, enumeration, and identification techniques do not account for viable but noncultivable bacteria. Although coliform bacteria are adequate indicators of bacterial pathogens, they do not predict the inactivation or removal of enteric protozoa and viruses. There are currently no practical techniques for assessing the viability of protozoan cysts or oocysts. Standard cell culture methods that use cytopathic effects have been limited to the detection of well-known enteroviruses and do not account for many other human viruses that may be found in water.

New analytical techniques for rapid detection of health-related microbial contaminants, such as the polymerase chain reaction technique, also have limitations. For example, this technique is a qualitative measure of the presence of an organism's nucleic acid and is unable to determine microorganism viability. There are also issues regarding sample interference and the test's sensitivity.

Contamination monitoring tools need to be advanced. Tools for monitoring microbial contamination in reclaimed water thus need to be advanced. Sophisticated models are being developed that calculate a distribution of risk over the population by using epidemiological data such as incubation period, immune status, duration of disease, rate of symptom development, and exposure data.[11] The limitations of microbial detection methods and other complicating factors cast great uncertainty on the assessment of potential risks from microbial contamination of reclaimed water. This calls for a conservative practice in pathogen removal where these projects are concerned.

Available techniques should be used to assess microbial risk. Potable reuse projects should use available techniques to assess microbial risk. They should also consider the range of consumers of the reclaimed water. In particular, the report recommends the following steps.

• When risk is assessed, potable reuse projects should consider using some of the newer analytical methods, such as biomolecular methods, as well as indicator microorganisms such as *Clostridium perfringens* and *F*-specific coliphage virus, to screen drinking water sources derived from reclaimed water. These screening methods should complement the bacterial and cell culture methods currently used for detecting pathogens in water. This risk assessment is recommended in addition to—not as a substitute for—aggressive treatment to ensure that pathogens of all kinds are removed.

• Risk estimates should take into account effects that pathogens may have on sensitive populations and the potential for secondary spread of infectious disease within a community. The sensitive portion of the population consuming tap water will be the most likely to be affected, and the potential for secondary spread of disease is an important, though difficult to quantify, aspect of understanding the risk of infectious diseases.

Epidemiological studies have taken an ecological approach. The few epidemiological studies that have been directed at indirect potable reuse have taken an ecological approach. This is an appropriate first step when health risks are unknown or poorly documented; however, negative results from such studies do not prove the safety of the water in question. Those studies can only be considered preliminary examinations of the risks of exposure to reclaimed water. Epidemiological data that can be confidently applied to the potable use of reclaimed water are lacking, and the results of epidemiological studies should be interpreted with caution. The potential for systematic and random error and potential biases should also be recognized.

Assessment of risks posed by chemical contaminants in reuse systems is also fraught with complications. Conventional toxicological testing strategies developed in the food and drug industries, as well as similar testing protocols recommended by NRC in its 1982 report, stress the use of concentrates of representative organic chemicals in both in vitro (cell culture) and in vivo (whole animal) tests. However, these approaches have several critical limitations. These include uncertainty regarding whether the concentrates used for testing are truly representative of those in the wastewater, higher-than-expected occurrences of false-negative results, long lag times between sample collection and the availability of results, difficulty in tracing results to particular constituents, and lack of suitability for continuous monitoring. Such approaches are also extremely costly and time-consuming.

Potable reuse systems should take steps to reduce existing and potential health risks posed by microbial pathogens.

Negative results do not prove safety. As mentioned earlier, negative results cannot be taken as proof of safety. To overcome these limitations, researchers are advised to develop an alternative toxicity testing approach using whole animals, such as fish. Such a test system could be used to conduct preliminary risk assessments of potable reuse projects and would also allow continuous toxicological monitoring of the reclaimed water.

Guidelines help assess risk from chemical contaminants. Potable reuse projects should use the following guidelines in considering risks from chemical contaminants.

• The need for toxicological testing of water is inversely related to how well the water's chemical composition has been characterized. If water contains few or very low concentrations of chemicals or chemical groups of concern, the need for toxicological characterization of the water may be substantially reduced. Conversely, if a large fraction or high concentrations of potentially hazardous and toxicologically uncharacterized organic chemicals are present, toxicological testing will provide an additional assurance of safety.

• For any toxicological test used for reclaimed water, a clear decision path should be followed. Testing should be conducted on live animals for a significant period of their life span. If an effect is observed, risk should be estimated using state-of-the-art knowledge about the relative sensitivity of the animal and human systems, and, if warranted, risk should be further defined by more research. This decision path is workable if the underlying basis of the biological response in question is understood (for example, endocrine disruption). For some health outcomes, such as carcinogenesis, the mechanism is less well understood, and an observed effect may have to be accepted as implying an effect on human health.

• Toxicological testing standards for reclaimed water should be supplemented by strict regulation of the processes for "manufacturing" the water. Processes for manufacturing the reclaimed water (that is, the treatment systems and environmental storage employed) need to be carefully considered and regulated on a project-by-project basis.

Reliability and quality must be ensured

Because of the many uncertainties associated with assessing and controlling chemical and microbial contaminants in potable reuse systems, it is essential to provide multiple barriers to contamination. For drinking water systems, the term "barriers" includes watershed protection programs, engineered treatment processes, and maintenance of the water distribution system infrastructure. In the case of potable reuse, barriers include industrial pretreatment programs, treatment processes, and environmental buffers. Including an environmental buffer in a potable reuse project as a barrier to contaminant transmission to consumers can substantially reduce public health risk. However, the public health benefit of an environmental buffer cannot be assessed with any precision given the current state of the art. The benefits that do accrue are likely to be associated with reduction in contaminant concentration and the introduction of a lag time. Environmental buffers that use aquifer storage appear to provide more protection than those with surface water storage. Soil aquifer treatment adds a further dimension of potential contaminant reduction. When surface water storage alone is used, more sophisticated treatment or longer storage times should be required, and short-circuiting should be a special concern. Short-circuiting occurs when treated wastewater influent either fails to fully mix with the ambient water or moves through the system to the drinking water intake faster than expected.

Public health surveillance can support quality assurance. Public health surveillance programs are also important components of quality assurance for potable reuse systems because they can provide early warning of possible health problems. Surveillance is distinct from epidemiological studies in that it is an ongoing public health program analogous to continuous monitoring. Findings identified in surveillance programs may generate hypotheses that epidemiological studies could test.

> **Giardia, Cryptosporidium, and enteric viruses are the three types of organisms of greatest concern in the design of potable reuse systems.**

The following range of quality assurance measures are recommended for potable reuse systems.

- Multiple, independent barriers to contaminants should be used. These barriers should be evaluated both individually and together for their effectiveness in removing each contaminant of concern. The cumulative capability of all barriers to accomplish removal should also be evaluated. This evaluation should consider the concentrations of the contaminant in the source water.
- Barriers for microbiological contaminants should be more robust than those for forms of contamination posing less acute dangers. The number of barriers must be sufficient to protect the public from exposure to microbial pathogens even if one of the barriers fails.
- Because performance of wastewater treatment processes may vary, such systems should use quantitative reliability assessments to gauge the probability of contaminant breakthrough among individual unit processes. "Sentinel parameters" should be used to monitor critical processes that must be kept under tight control. These parameters indicate treatment process malfunctions that are readily measurable on a rapid (even instantaneous) basis and that correlate well with high contaminant breakthrough.
- Utilities using surface water or aquifers as environmental buffers should prevent short-circuiting. In addition, the buffer's expected retention time should be long enough—probably six to 12 months, as outlined in proposed California regulations—to give the buffer time to remove additional contaminants. Such a lag time also allows public health authorities to take action if unanticipated problems arise in the water reclamation system.
- Potable reuse operations should have alternative means for disposing of reclaimed water if it does not meet required standards. Alternative disposal routes protect the environmental buffer from contamination.
- Every community using reclaimed water as drinking water should implement well-coordinated public health surveillance systems to document and possibly provide early warning of any adverse health events associated with its ingestion. Surveillance systems must be jointly planned and operated by health, water, and wastewater departments and should identify key individuals in each agency to coordinate planning and rehearse emergency procedures. Appropriate interested consumer groups should also be involved with and informed about the public health surveillance plan and its purpose.

Operators need special training. Finally, operators of water reclamation facilities should receive training regarding the principles of operation of advanced treatment processes, the pathogenic organisms likely to be found in wastewater, and the relative effectiveness of the various treatment processes in reducing contaminant concentrations. These operators need training beyond that typically provided to operators of conventional water and wastewater treatment systems.

Summary

The US population continues to grow, but available water resources do not. The quality of existing water resources continues to be impaired by wastewater discharges, which are increasing in volume as the population grows. Some of the nation's most rapidly growing population centers are in arid climates. These factors lead to a greater need for alternative water supplies. Thus, some communities have turned to planned, indirect potable reuse to help fulfill that need. Indirect potable reuse is a viable application of reclaimed water under appropriate circumstances. However, any community considering potable reuse should do so only after a careful, thorough, site-specific assessment that includes contaminant monitoring, health and safety testing, and system reliability evaluation.

Interest in indirect potable reuse of municipal wastewater has grown significantly in recent years, and possible health effects have been evaluated at a few locations, including at an existing project in Los Angeles County, Calif., and a pilot-plant study in Tampa, Fla. A demonstration plant in Denver, Colo., also performed research on direct reuse of wastewater. The limitations of epidemiological studies and currently used toxicological techniques notwithstanding, no adverse health effects were identified in any of these studies (Table 1).[4,6,12–17] Although such results are encouraging, this information is much too limited to allow extrapolation to potable reuse projects in general. In fact, the safety of each project is a function of the nature of the wastewater, the type of wastewater treatment, the extensiveness of the advanced wastewater treatment, the detailed character of the environmental buffer, and the nature of the drinking water treatment provided. For the foreseeable future, a detailed site-specific assessment will be required for every potable reuse project.

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