Direct potable reuse
Then and now

Advances in direct potable reuse technology (DPR) ensure that it can provide the highest quality of drinking water regardless of source quality. **Joseph A. Cotruvo** provides a historical perspective of potable water reuse from the late 1960s to the present and offers his expert views on DPR issues that need to be resolved.

Potable wastewater reuse at a public level has existed since the dawn of civilization when human settlements were established and human waste and surface runoff were discharged into rivers. Indirect potable water reuse (IPR) has been either inadvertent or deliberate where untreated and then treated waste discharges occurred upstream and the more or less diluted wastewater is transported downstream and received in drinking water intakes, where it is usually treated to acceptable drinking water standards.

DPR dispenses with the intermediate environmental phase and the waste stream is treated to drinking water quality and piped to consumers. Direct potable reuse was initiated on a large scale in 1968 in Windhoek, Namibia. After a long hiatus where the technology, safety, and feasibility were being evaluated, numerous projects are now in progress. The technology has developed to the point where today regardless of source quality, it can provide water that is as pure as the best natural water, and certainly higher quality than conventional public drinking water produced from most surface waters.

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Several levels of technology and practice illustrate the progression of reuse from wastewater to final product drinking water.

- Unplanned or deliberate IPR: Untreated or treated upstream surface water discharge downstream to a municipal drinking water plant.
- Planned IPR: Groundwater recharge through soil aquifer treatment(SAT) or injection of highly treated water.
- Planned IPR: Advance-treated wastewater with surface discharge to a water body or groundwater recharge.
- IPR/DPR: Advance-treated wastewater discharged to the entry of a drinking water treatment plant, or post treatment blending, or storage in a surface or groundwater prior to distribution.
- Pipe-to-pipe DPR: Treated wastewater to drinking water distribution without an environmental buffer.

In the USA an historic milestone occurred in 1980 when the US Environment Protection Agency's (EPA) Office of Drinking Water (ODW) organized a conference entitled "Protocol development: Criteria and standards for potable reuse and possible alternatives." About 100 experienced scientists and engineers participated in the six subgroups that addressed the questions. The conference examined the state-of-the-science in potable water reuse and assessed water quality, best available treatment technology, reliability, analytical chemistry, microbiology, toxicology, and human health issues. The attendees were asked to recommend basic principles that would assist decision-making, and specific studies that would address the remaining questions. Since then, the DPR environment and knowledge base has improved significantly.

Pre-1980s source water

The general quality of many surface water sources in the United States before the 1980s was poor. Historically, discharges to surface waters were largely uncontrolled so microbial and chemical contaminants reached undesirable levels in many major and lesser rivers.

The Clean Water Act of 1972 and amendments of 1977 were a few years old and were in the process of being implemented. Universal secondary treatment requirements for municipal wastewater discharges to surface waters were being implemented, but not yet fully. A list of priority industrial pollutants had been identified in 1977 as the result of a negotiated settlement of a lawsuit brought by an environmental group against EPA. Pretreatment regulations were beginning to be implemented, so discharges to municipal sewers from industrial facilities were often significant. Effluent limitation guidelines were being produced for industrial source categories and were beginning to be implemented. They are technology-based US standards for waste-water discharges to surface waters and municipal treatment plants. Since the mid-1970s, effluent limitation guidelines have been published for at least 58 industrial categories. These treatment requirements prohibit discharges of billions of pounds of pollutants annually into US surface waters.

In the municipal drinking water sector, the Safe Drinking Water Act of December 1974 was being implemented. The first interim primary regulations of 1975 were derived from existing public health service standards, so they reflected early but not current information.

The first modern drinking water regulations were for trihalomethanes (THMs) that had been identified along with other disinfection byproducts of chlorination. Later, regulations were developed for volatile industrial chemicals (VOCs) and other contaminants. The chemistry of chlorine demand had not been investigated or understood. THMs that were regulated in 1978 created a shock in the drinking water community because they linked beneficial disinfection processes with concurrent production of potentially harmful chemicals in drinking water. Regulations under the Safe Drinking Water Act for control of underground injection practices were also new. Regulations under the Federal Insecticide, Fungicide and Rodenticide Act (1972 et seq) that controlled registration of pesticides were newly forming so many undesirable persistent pesticides were still being widely applied, and some were migrating to surface waters.

State of water science and technology

In 1980, the applications of gas chromatograpy and mass spectrometry to drinking water were still novel and few water laboratories had those instruments. Gas chromatography was being applied for analyses of THMs and volatile synthetic organic chemicals (VOCs) such as trichloroethylene, but there were minimal data on higher molecular-weight, synthetic, organic chemicals in water. In water microbiology, the historically common measurements were on total coliforms and E. coli or fecal coliforms and heterotrophic plate counts (HPC), but very little information was available on viruses and giardia, and cryptosporidium in drinking water sources was just beginning to be studied.

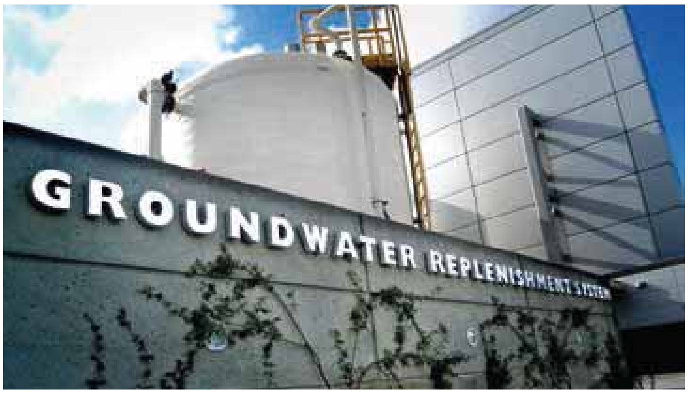
The conventional drinking water treatment technologies were coagulation, sedimentation, sand filtration, and chlorination and they were routinely applied to impaired surface waters. A few plants used powdered activated carbon (PAC), or sand replacement granular activated carbon (GAC) for taste and odor. In Europe, some plants were using ozone, chlorine dioxide, and granular activated carbon, but very few United States plants used these methods. Membranes were in their early days of consideration, but mostly for desalination.

Groundwater recharge and soil aquifer treatment were being used in some locations. The Water Factory 21 in Orange County, California was developing advanced treatment systems for groundwater recharge primarily as a seawater intrusion barrier.

1980 Potable Reuse Conference recommendations

Operating in the 1980 technical information context, the EPA Office of Drinking Water's conference developed a series of recommendations aimed at providing a substantial basis for considering the safety and practicality of potable reuse as a means for producing high-quality drinking water where needed. Major recommendations included:

- Standards should be developed to define the acceptable quality of potable water regardless of source.
- There was need to develop detailed characterizations of source waters and finished waters.
- The toxicology of water with trace concentrations of chemical mixtures should be evaluated. Concentrate animal feeding studies were suggested.
- More stringent microbiological requirements were desirable.



Groundwater replenishment system in Orange County, California, USA

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- Reasonable cost treatment technologies with greater efficacy and reliability needed to be developed, and treatment trains needed more redundancy. Multiple barriers are essential.
- There should be greater usage of groundwater recharge.
- More non-potable reuse options should be developed and applied.
- Public perception and public education and social acceptability of reused water were important considerations to be addressed in any proposed reuse project.

Progress since 1980

Most of those recommendations have come to fruition and the environment for direct potable reuse has reached the point where it is a fully available and safe option for producing drinking water where it is needed. The water industry has arrived in the 21st century having made gigantic scientific, technological, and management progress.

The quality of wastewaters and source waters has improved significantly. Minimum secondary treatment and often tertiary treatment technology is virtually universally applied in the United States. Industrial chemical discharges have been controlled to a great degree by regulation and effluent control guidelines by industrial sector, and also due to reduced heavy industry activity. Pretreatment requirements are in place for chemical discharges to municipal sewage systems. The "Priority Pollutants" list is to some degree an anachronism due to the effluent controls that have been implemented. The science of water analysis has developed exponentially to the point where chemical analyses at the parts per billion and parts per trillion levels are almost routine.

With regard to drinking water standards and guidelines, there are now about 100 Maximum Contaminant Levels (MCLs) and surrogate standards and comprehensive filtration and disinfection requirements. In addition there are more than 200 non-regulatory EPA Drinking Water Health Advisories, and 363 pesticide human health benchmarks for drinking water that provide interpretative toxicology-based chronic exposure levels in the event that a chemical is detected in drinking water.

The recommended whole animal testing of water concentrates did not pan out. That was partly because chemical transformations and losses can occur during the production of concentrates, but also because adverse effects were usually not detected. In vitro testing of concentrates did sometimes detect activity, but specific causes and human health significance were not generally determinable.

Treatment technologies including microfiltration, ultrafiltration, nanofiltration, and reverse osmosis membranes are becoming widely used in municipal and other applications. Advanced oxidation technologies using ozone or hydrogen peroxide, and ultraviolet light are being used in several water recycling applications.

On-line real-time monitoring and data management systems are in common use in drinking water plants to provide for much greater control of water quality and operations. Hazard Assessment and Critical Control Point (HACCP) management approaches are highly desirable.

One consequence of the advances in analytical chemistry detection levels is that trace levels of pharmaceuticals and natural and consumer products are now detectable in wastewaters and some drinking waters. Even though their concentrations are minute, and almost always well below levels that could cause a plausible risk of adverse effects from consumption, their presence in trace quantities raises questions and some uncertainties among consumers and some regulators.

My conclusions

The quality of wastewater sources in the United States has improved to a significant degree since the 1980 reuse conference because of regulatory and technological advances.

It could be said that the 1980 conference participants were prescient and forward thinking because since then scientific and health assessments in addition to technological advances have resolved most of their issues and recommendations. Technological progress has established that water sources being highly impaired does not preclude their use as drinking water sources, and these are valuable resources that should be productively used.

My template of principles for moving forward includes:

- An aggressive pretreatment program should be part of any DPR project to prevent introduction of refractory and difficult-to-treat or toxic chemicals into domestic wastewater sources.
- Numerous technological options and treatment combinations are capable of producing high quality DPR product.
- Multiple barriers and redundancy are essential so that the treatment efficacy is assured in the event of an unplanned quality excursion.
- The principal health concerns in DPR and IPR are acute microbial risks, and these have been resolved by the availability of proven appropriate disinfection and membrane technologies and multiple barriers.
- Treatment (e.g. secondary or tertiary) standards and/or microbial specifications should be developed so that the necessary performance parameters for the advanced treatment system can be rationally determined with appropriate margins of safety. This narrows the concentration range of contaminants that challenge the advanced treatment, as well as reducing the physical stress on that technology.
- Inorganic chemicals and radionuclides are readily controlled. The issues associated with trace organic chemical detections are probably more philosophical than actual public health concerns, because when they are detected the concentrations are so low that they are several orders of magnitude beyond the capability of toxicological science to demonstrate biological effects in test animals and humans. If any, these would be in the category of potential chronic risks and not the type that generally would require emergency actions by the water authority or health officials in the event of a temporary deviation from the performance specifications. For example, the few pharmaceuticals detected after some treatment trains are usually at concentrations millions of times below therapeutic dosages. However, they will continue to be issues because chemical detection limits will continue to decline so detections at levels of even less potential significance are bound to increase. Thus *de minimis* risk quality goals should be established rather than using detection limits.
- Monitoring capabilities and process management are much improved and on-line real-time monitoring for numerous process performance indicators is now available and in widespread use. Numerous treatment configurations are available and more are in development. Some seem to be overkill because the quality of the water capable of being produced by many of them is well beyond current widely used conventional drinking water technologies that are applied to natural and unplanned reuse systems.
- Consistent and reliable process performance operations are essential. Some level of piloting and a rigorous system shakedown period

are always desirable, especially for training operating personnel. Continuous reliability is expected and an alternate diversion and water option should be available for some extreme acute short-term deviations that might possibly occur, but are extremely unlikely because of the multiple barrier design. These would not be different than might be encountered in a conventional drinking water supply.

- A small, manmade storage buffer would be useful for water distribution management as well as to provide an opportunity for some analytical validation, if desired. Use of an environmental buffer, such as a surface reservoir or groundwater placement, is an inviting concept but of questionable value. An intervening environmental passage does have the psychological effect of separating wastewater identity from drinking water in the minds of the public and some regulators. However, placing highly treated water into an uncovered, unlined and probably not fully protected reservoir is likely to be counter-productive, because it re-contaminates the already very high quality water with microbial and other contaminants. The ostensible use of the reservoir for die-off of hypothetical recalcitrant microbial contaminants is not supportable, because that treatment system should have been designed and operated with sufficient multiple barriers to reliably prevent their transport and survival. Ground-water passage is appropriate for water storage and transport, but not meaningful for contaminant reduction, because it could add contaminants to the already highly treated water from the geology, as has been known to occur.
- Consumer and ratepayer acceptance and support for the initiation of the potable reuse project are essential. Of course, the quality and safety of the water must be assured, but the key factor is a consensus that the additional water is essential in the community for its functioning and perhaps to ensure protection from droughts. Whether or not all consumers actually drink the water is a matter of personal preference; the same issue exists in many conventional drinking water supplies due to consumers being bombarded with negative water quality news, which is often exaggerated or misguided. On the other hand consumers may retain a "yuck factor" concern because of the impaired source, or simply decline because of taste preferences, because they have drinking water options that include bottled water or point-of-use treatment devices. So, universal drinking water consumption should not be the principal element of the public education program, or required for success. However, it is essential that the water supplier has developed a high level of trust and confidence within the community. This is maintained by meeting all standards and guidelines, candid communications, and rapid implementation of corrective actions when needed.
- Unified drinking water regulations rather than separate reuse-specific regulations are required to provide a consistent basis for progress in applications of IPR and DPR. A few key parameters relevant to DPR should be added to the current standards rather than developing separate IPR/DPR quality standards.

DPR/IPR projects in Namibia, USA, and space

Windhoek, Namibia

The original, large-scale pipe-to-pipe DPR project is still operating in Windhoek. Its original treatment train included ferric chloride, coagulation, dissolved air floatation, rapid sand filtration, granular activated carbon, chlorine, and sodium hydroxide before blending with the "natural" water. That water is now used for irrigation only. In 1997, the process was changed to include powdered activated carbon, pre-ozonation, ferric chloride and polymer, coagulation, dissolved air floatation, potassium permanganate, rapid sand filtration, ozone, biological activated carbon, granular carbon, ultrafiltration, chlorine, and sodium hydroxide. The blend is now about 30 percent recycled water.

Orange County and others in California

The Orange County system has progressed from the Water Factory 21 configurations to groundwater replenishment and a seawater intrusion barrier. The process begins with secondary effluent that has either been produced by activated sludge or trickling filter, chloramine, microfiltration, cartridge filter, three-stage reverse osmosis, advanced oxidation with hydrogen peroxide/ ultraviolet light, carbon dioxide stripping, and lime stabilization. The advanced oxidation process was included primarily because of the detection of 1,4-dioxane and dimethylnitrosamine. Dioxane is a solvent that was found in the source water and it is not very biodegradable and it is not well removed by RO. Some dimethylnitrosamine was found in source water, but most is probably produced by chloramine reactions with wastewater organic precursors such as dimethylamine in the water treatment process. The dioxane is removed by the hydroxyl radical oxidation process, and the dimethylnitrosamine is primarily removed by UV photolysis. Part of the product water is transported to percolation basins for groundwater recharge and ultimate withdrawal without further treatment, and part is injected along the coast as a seawater intrusion barrier. The original 265 million liters per day (mld) or 70 million gallons per day (mgd) facility is now being expanded to 379 mld or 100 mgd.

Los Angeles has a history of successful soil aquifer treatment going back to the 1962 Montebello Forebay Groundwater Recharge Project among several functioning groundwater recharge spreading and injection projects in Southern California. San Diego and Los Angeles are engaged in developing additional large-scale IPR/DPR water reuse projects.

Space stations

The National Aeronautics and Space Administration has used recycled water in the space stations for consumption for many years. The source water is urinary distillate and air condensate recovery. The process includes multifiltration, vapor compression distillation, catalytic reactor, ion exchange, and iodine disinfection.

Cloudcroft, New Mexico and Big Springs, Texas.

Several projects are in development in the southwestern United States because of drought-driven water shortages. Generally, these projects use membrane bioreactors or conventional secondary effluents, MF, and RO membranes, advanced oxidation, and blending with natural water to be treated in a drinking water facility. These might be considered hybrid IPR/DPR facilities.

Domestic commercial potable recycle projects

There was a system for household recycling developed by the Pure Cycle Company in 1976 that was discontinued. It involved recycling household wastewater that was treated by grinding, a biodisk/cloth filter, MF, ion exchange, ultraviolet light, and storage. At least one other system is now being developed by another company and undergoing late-stage testing.

Several US states are working toward regulations or guidelines for DPR, but the federal EPA is not. For that reason, the WateReuse Association, in collaboration with the National Water Research Institute and several other water provider organizations, has initiated a process to develop consensus science-based guidelines to provide a uniform set of credible principles and recommendations that would be accessible to all potential DPR/IPR project developers and regulators, and obviate the need for them to revert to reexamining all of the complex issues involved.

Author's Note

Dr. Joseph Cotruvo is president of Joseph Cotruvo & Associates, a water, environmental, and public health consulting firm. He serves on the WHO committees that develop the Guidelines for Drinking Water Quality. Previously, he was the first director of the Drinking Water Standards Division of US EPA's Office of Drinking Water, developing the Drinking Water Health Advisory System and numerous National Drinking Water Quality Standards and Guidelines. He was also director of the EPA's OPPT Risk Assessment Division, and was vice president for Environmental Health Sciences at NSF International. He was chairman of the Water Quality Committee of the Board of Directors of the District of Columbia Water and Sewer Authority. He is active in water reuse development activities including serving on scientific oversight committees for several municipal water reuse projects, and as chairman of the National Regulatory Committee of the WateReuse Association. For a complete listing of supporting documents, contact the author by email at: joseph.cotruvo@verizon.net.