ARROYO

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Water Resources Research Center • College of Agriculture and Life Sciences • The University of Arizona

Once Shunned, Wastewater Now Viewed as a Valuable Resource

Reclaimed, recycled, reused water—all one and the same, all sources of renewable supplies

Everyone agrees Arizona is dry. Even where rainfall is most plentiful, along the Mogollon Rim, annual precipitation is low compared to most other states.

Although dryness is a way of life in Arizona, its economy and population have grown, even flourished, on the development and management of ample water supplies: rivers flush with melting snow and runoff from summer rainstorms, large, productive aquifers and a relatively recent resource, the Central Arizona Project, which for years delivered more Colorado River water to central Arizona than could be directly used.

Despite these resources, Arizona remains dry and according to climate scientists, likely to become even drier in the future. What at one time were considered ample water supplies now appear limited, perhaps even insufficient in the face of drought and expanding demand.

One of the keys to solving the West's water-supply problems, therefore, is finding smart, innovative ways to reuse water we already have. Wastewater is now recycled for a range of non-potable uses. In the future, as needs continue to grow, reclaimed water may well be polished and purified for potable use.

Many questions will have to be answered, however, and many issues of public concern resolved. This poses a challenge to water managers who need to consider various technical and legal issues. Further, outreach and public education will be essential as managers and policy makers work through complex, interrelated issues.

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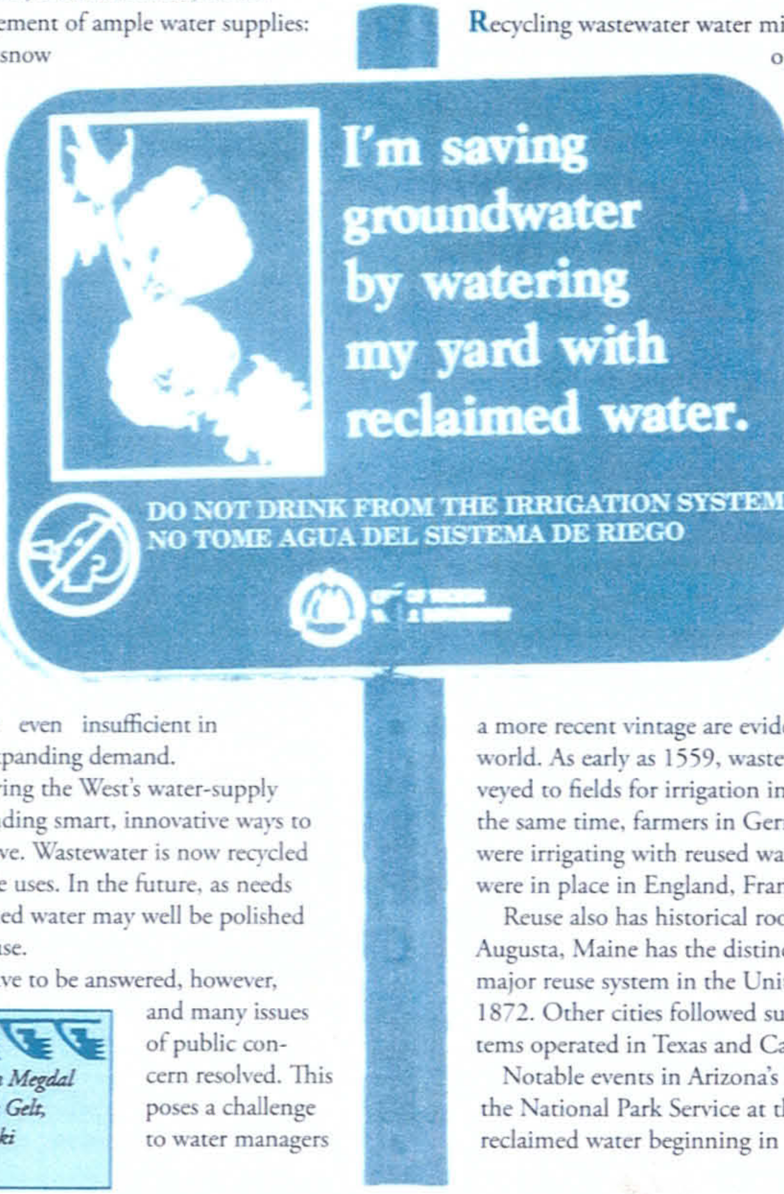

Historical Reuse

Recycling wastewater water might seem like a recent development. Ancient civilizations, however, reused water. The English sanitary engineer Baldwin Latham found what he believed to be evidence of sewers and irrigation areas in the ancient city of Jerusalem. The Chinese and Japanese relied on sewers and irrigation to dispose of their sewage for thousands of years. Waste from densely populated areas was either collected to be spread directly on the fields or discharged into small streams or canals for irrigation.

Historical precedents of a more recent vintage are evident in other parts of the world. As early as 1559, wastewater was collected and conveyed to fields for irrigation in Bunslau, Prussia. At about the same time, farmers in Germany and Scotland also were irrigating with reused water. By 1900, reuse systems were in place in England, France, Mexico and Australia.

Reuse also has historical roots in the United States. Augusta, Maine has the distinction of having the first major reuse system in the United States, constructed in 1872. Other cities followed suit; by the 1900s such systems operated in Texas and California.

Notable events in Arizona's history of reuse include the National Park Service at the Grand Canyon using reclaimed water beginning in 1926 to flush toilets, irri-

Water Reuse Has Significance on Many Levels

Water reuse is a many faceted concept that takes on different images when viewed from different perspectives. Looked at as wastewater treatment plants processing and distributing water to irrigate turf, it appears unglamorous at best. Seen from other angles, it can take on new meaning and significance.

Global

Consider the global perspective: water we use today, whether groundwater or surface water from lake or river, existed throughout time. Water in your glass has been recycled innumerable times, having traveled through the hydrologic cycle as precipitation, runoff, infiltration, discharge to oceans and lakes, and evaporation and transpiration before filling your glass to quench your thirst.

Regional

Water cycles from use to waste to use again many times in large river systems.

"As water scarcity increases, society becomes more intimate with the hydrologic cycle. In fact, we create our own subcycle of water within the hydrologic cycle. As evidence, consider that all of the wastewater from Las Vegas is discharged to Lake Mead, a reservoir on the Colorado River.... Las Vegas' wastewater treatment plant effluent becomes a source of supply for all downriver users." *–Guy Carpenter, HDR*

Personal

If reuse is a fact of nature it also can have personal, even poetic significance. There is a simplicity and purity about western author Wallace Stegner's description of his frontier family recycling water in the early twentieth century: "You boiled sweet corn, say. Instead of throwing the water out, you washed the dishes in it. Then you strained it through a cloth into the radiator of your car, and if your car should break down you didn't leave the water to evaporate in its gullet, but drained it out to water sweet peas."

gate landscape and for dust control. According to Steve Rossi in Phoenix's Water Services Department, Phoenix was reusing wastewater as early as 1932, when effluent from the 23rd Avenue Waste Water Treatment Plant was conveyed to Peterson Farms, where it was stored in septic tanks and used for irrigation.

Reclaimed Water, a Distinctive Water Resource

From this early reuse in Arizona to the present, reclaimed water has developed as a distinctive water resource. A key distinction, wastewater is the only water source that has the seemingly miraculous quality of increasing as population expands: more people equal more wastewater equals more potential reclaimed water.

Reclaimed water is also distinctive in its legal status. In Arizona law, treated wastewater is neither groundwater nor surface water. As a result of a 1989 State Supreme Court decision, effluent has been relegated to a hydrological purgatory awaiting legislative action to determine its legal status. The case (Arizona Public Service Company v Long) involved Phoenix area cities' efforts to sell effluent to cool the proposed Palo Verde nuclear generating station. The sale would disadvantage two ranches that had been using the effluent discharged to the Salt River channel. The ranchers challenged the right of the cities to sell the effluent to the nuclear plant. The case went to the Arizona State Supreme Court.

Arizona water law recognized two types of water, surface water and groundwater. The effluent consisted of both groundwater and surface water. If effluent were considered surface water, it belonged to the river's appropriators; if groundwater, it would be regulated by the Groundwater Management Code, with its restrictions on transportation.

The Court took a middle course, holding that effluent was neither groundwater nor surface water and therefore not regulated by laws pertaining to either. After stating what effluent was not, the Court concluded it is nonetheless water under Arizona law, a public resource subject to regulation. It was up to the Arizona State Legislature to take up the issue as it saw fit.

So far the Legislature has not seen fit to act on the issue. As a result, effluent is a legally distinct type of water in Arizona with a unique status among water resources: governments and utilities are free to sell reclaimed water like any other commodity.

Reclaimed water's rags-to-riches story lends it further distinction. Once considered a nuisance to be disposed of as cheaply as possibly, reclaimed water now is considered a valuable asset. Its potential as a water resource has expanded as more efficient treatment methods have been developed. Recognizing the value of the resource, the State has adopted policies that encourage greater water reuse through incentives embedded in regulatory programs, and water providers are developing reclaimed water as an essential component of their water supply portfolios.

Although the perceived value of reclaimed water has been on the rise, there remain concerns about its use. Some of these concerns are embedded in culture: reclaimed water is uniquely burdened by its association with "impurity." Regardless of how clean it has been scrubbed, it carries the trace of its source.

In an interesting instance, of national notoriety, operators of the Snowbowl, a ski resort in Flagstaff, planned to make artificial snow with reclaimed water. The peaks where Snowbowl is located are sacred to the Hopi and Navajo, who turned to the courts to prevent implementation of the plan. They argued that using reclaimed water dishonors the peaks and interferes with the exercise of their religious beliefs. The case has been making its way through the courts, and may reach the U.S. Supreme Court. A judge of the 9th U.S. Circuit Court of Appeal, which ruled in favor of the tribes, said permitting the use of treated effluent on the peaks would be equivalent to the government requiring Christian baptisms be done with reclaimed water. Although that judgment was overturned on rehearing, the analogy still resonates with many people.

Water Quality Regulations

The central issue in water reuse is quality: actual and perceived. The central challenge is to provide the right quality for the intended

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Reclaimed water classes, standards and uses.

Class	Treatment	Fecal coliform standard 4 of 7 daily samples // single-sample max.	Turbidity standard 24-hour average // single-sample max.	Nitrogen standard 5-sample geometric mean concentration	Allowed Uses
A+	Secondary treatment, filtration, nitrogen removal, and disinfection	No detectable // less than 23 in 100 ml	Not to exceed 2NTUs // 5NTUs	Less than 10 mg/L	Irrigation of food crops; recreational impoundments; residential landscape irrigation; schoolground landscape irrigation; toilet and urinal flushing; fire protection systems; spray irrigation of an orchard or vineyard; commercial closed loop air conditioning systems; vehicle and equipment washing (not self-service washes); snowmaking
A	Secondary treatment, filtration and disinfection	Same as Class A+	Same as Class A+	N/A	
B+	Secondary treatment, nitrogen removal, and disinfection	Less than200 in 100 ml // less than 800 in 100 ml	N/A	Less than 10 mg/L	Surface irrigation of an orchard or vineyard; golf course irrigation; landscape impoundment; dust control; soil compaction and similar construction activities; pasture for milking animals; livestock watering (dairy animals); concrete and cement mixing; materials washing and sieving; street cleaning
B	Secondary treatment and disinfection	Same as B+	N/A	N/A	
C	Secondary treatment in a series of wastewater stabilization ponds	Less than 1000 in 100 ml // less than 4000 in 100 ml	N/A	N/A	Livestock watering (non-dairy animals; irrigation of sod farms; irrigation of fiber, seed, forage, and similar crops; silviculture

use. The Arizona Department of Environmental Quality, which regulates the use of reclaimed water, also regulates water quality for both surface and groundwater, ensuring the quality of water for recharge projects, constructed wetlands and discharge of effluent to stream channels and ground water. ADEQ requires extensive testing for a long list of substances and permits the discharge or reuse of water depending on the concentrations of these substances.

The Department regulates the use of reclaimed water through a permitting system. Different classes of water must meet specific criteria for specified uses. The higher the quality of water, the more uses it can serve.

Class A is the highest-quality reclaimed water, followed by B and C. Class A has been disinfected to be essentially pathogen free. The disinfection level is less in Class B and C reclaimed waters. Classes A and B may have "plus" designations, A+ and B+. The plus sign indicates that these waters have been further treated to reduce nitrogen compounds to no more than 10 milligrams per liter (mg/L).

Ten years ago the reclaimed water permitting system was revamped to make reuse more attractive to end users. Permits were simplified, making permits for A+ water very easy to obtain. Permits for lower quality class C water require substantially more record-keeping and reporting.

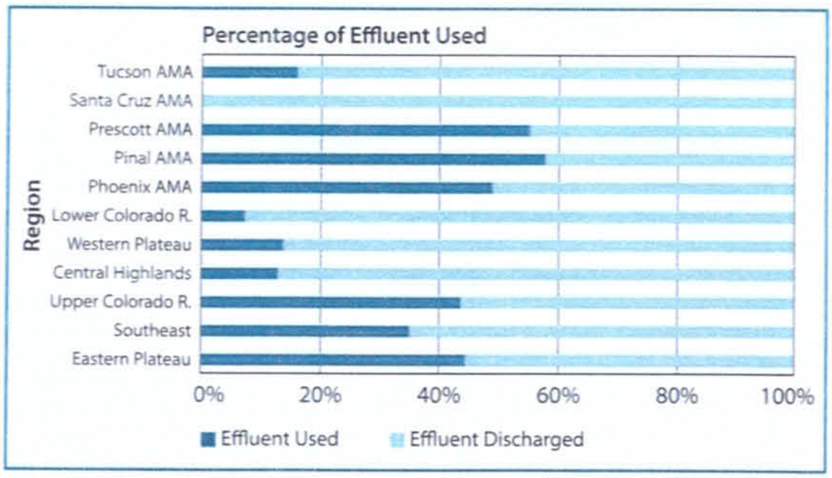
Chuck Graf, Associate Director of the Arizona Water Institute at ADEQ, says that the permitting system was constructed to encourage the safe use of reclaimed water. "We tried to create incentives for waste-water generators to treat the water to a higher quality, at the same time creating a larger pool of end users able to use the water," Graf says.

These incentives appear to be paying off. A+ and B+ water are by far the most often permitted classes, says Graf.

Proud of improved treatment and increased use of reclaimed water, ADEQ still holds a take-it-slow position on direct potable reuse of reclaimed water because of concerns for public health. Under reclaimed water rules even A+ water may not be put to any use where ingestion or body contact are possible; so use for swimming pools, misting systems, evaporative coolers and most uses inside the home are prohibited.

Uses of Reclaimed Water

Statewide, 2.5 percent of the total municipal, industrial and agricultural water demand, or about 200,000 acre-feet, is met with reclaimed water. In many areas water reuse provides important benefits. Cities like Flagstaff, Sierra Vista and Lake Havasu City are using reclaimed water to preserve their groundwater and surface water resources. Lake Havasu City uses about 2,300 acre-feet per



The estimataed percentage of effluent used in each of the AMAs and planning regions. Gaps in the effluent generation and use data make these percentages only rough estimates.

year for turf irrigation, Flagstaff uses about 1,650 acre-feet per year for golf courses and other irrigation, and Sierra Vista/Fort Huachuca stores about 2,800 acre-feet per year in underground storage facilities to protect perennial flow in the San Pedro River.

As is evident from the above, a major use of reclaimed water is to irrigate expansive turf areas such as golf courses, parks, cemeteries and highway medians. Such uses have served places like Tucson well, which until 1992 was entirely dependent on groundwater. Relying on a finite supply of water, the city faced the inevitable consequences of increasing costs for delivering decreasing supplies to ever more people. This caused some water managers and citizens to be critical of using precious potable supplies to water lush landscapes in the desert, and golf courses became disfavored water-wasting icons. Reclaimed water use redeemed golf courses, parks and other such facilities from the accusation that they waste potable water reserves. Even water-prudent members of the public could then enjoy such amenities.

Reclaimed water also is used to fill artificial lakes, sometimes described disapprovingly as fake lakes. Such lakes, mostly serving decorative and recreational purposes, were constructed to attract home buyers to new and expanding developments and to provide popular amenities. In Arizona, state laws and local ordinances encourage the use of reclaimed water rather than groundwater or other potable supplies to fill artificial lakes.

Reclaimed water also has industrial applications. Its use as cooling water for the Palo Verde Nuclear Plant is an example. Located west of Phoenix, Palo Verde is the nation's largest nuclear power plant and the only U.S. nuclear facility not located next to a large body of water. To meet its cooling water needs, the plant uses treated effluent from several area municipalities: more than 2 billion gallons (about 60,000 acre-feet) each year.

Arizona agriculture takes about 40 percent of the treated wastewater used in the state, and not all agricultural effluent use is counted in this figure. Many agricultural irrigators who use surface water are actually recycling the water used upstream. Effluent from Phoenix's 91st Avenue treatment facility, not used by the Palo Verde nuclear facility or the Tres Rios Ecosystem Restora-

Snapshots of Water Reuse at Work in Arizona

From north to south, from Flagstaff to Sierra Vista, Arizona cities and towns are reusing water for various purposes. The following brief descriptions tell of reuse projects occurring within the state.

Payson

The town of Payson, which experiences wide variations in water demand with the annual comings and goings of its summer residents and visitors, constructed Green Valley Park to provide reclaimed water storage for pumping to other reuse customers, watering the landscaping of Green Valley Park, and groundwater recharge to slow or reverse water table decline. Lakes in the park recharge the groundwater through percolation, in addition to offering a range of recreational uses, excluding only swimming and wading, which are prohibited.

Gilbert

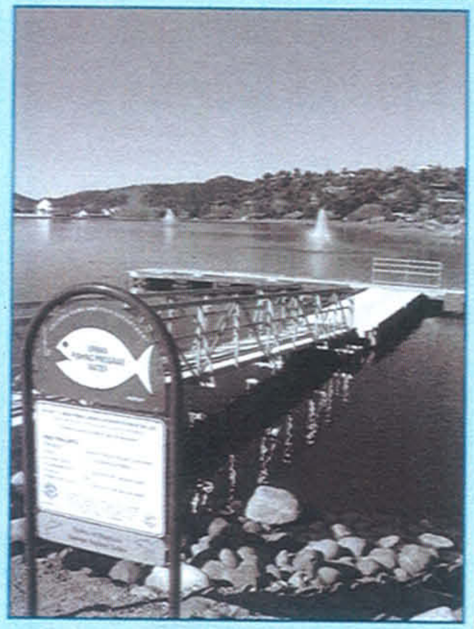
In 1986, the Town of Gilbert committed itself to reuse of 100 percent of its wastewater effluent and began the process of constructing facilities needed to meet this goal. The Town's 110-acre Riparian Preserve contains 7 recharge basins comprising 70 acres. The basins are filled on a rotating basis with treated effluent that is allowed to percolate into the aquifer where it is stored for future use. In addition, the Preserve provides habitat for more than 150 species of birds, as well as fish, amphibians, reptiles, insects, and mammals. An additional lake, filled with reclaimed water, is designated as an urban fishing resource by the Arizona Game and Fish Department. Trails, viewing blinds, a floating boardwalk and other feature provide educational and recreational opportunities for visitors.

Tusayan

Reclaimed water use began 10 years ago in Tusayan, near Grand Canyon National Park, when the Best Western Squire Inn built an onsite system. Coconino County requires all commercial and multi-family units built in Tusayan to install dual plumbing. A regional reclaimed water system has been distributing reclaimed water since August 2000, primarily for toilet flushing and irrigation. Today, almost 40 percent of Tusayan's total water use is supplied by reclaimed water.

Flagstaff

The strain on developed water supplies in Flagstaff led voters in 1990 to approve construction of the Rio de Flag Wastewater Reclamation Plant. Two decades later, on summer days almost all



The reclaimed water beckons visitors to Payson's Green Valley Park fishing lake, but no swimming. Photo courtesy of Eric Swanson of the Arizona Game and Fish Department.

of the reclaimed wastewater produced by the Rio de Flag plant is used. On days of peak use, reclaimed water can account for as much as 25 percent of all the water used citywide. Consequently, Flagstaff is retrofitting the Wildcat Hill plant to increase the supply of reclaimed wastewater by bringing its effluent to Class A+ quality, too. Reclaimed water is available for irrigation to residential users who have distribution lines adjacent to their property. As of January 2008, there were 18.3 miles of reclaimed water distribution line providing water for irrigation and construction related uses.

Sierra Vista-Fort Huachuca

Sierra Vista is recharging about 2,200 acre-feet per year of reclaimed water to preserve water supplies and protect river flows through the San Pedro River Natural Conservation Area, and Fort Huachuca reuses effluent to irrigate their parade fields and golf course and is nearing completion of a recharge project that will bring the total reclaimed water use up to 1,000 acre-feet per year. Other communities in the San Pedro sub-watershed are looking for ways to increase their water reuse, as well. Bisbee, Huachuca City and Naco all are working with the assistance of the Upper San Pedro Partnership on cooperative conservation efforts involving reuse of reclaimed water.

tion Project, flows in the Salt River channel to the Buckeye Water Conservation and Drainage District, which delivers the water to agricultural users.

The use of reclaimed water in two Indian water rights settlements demonstrates its flexibility and potential for creative use. Written into the 2004 Gila River Indian Community settlement is a reclaimed water exchange provision between the tribe and the cities of Mesa and Chandler. Per this innovative provision, the cities will exchange reclaimed water for part of the tribe's CAP water, on a 5 to 4 ratio. The exchange increases the tribe's agricultural water supplies, while the cities gain potable water for their citizens. A reclaimed water exchange agreement also figures into the 2004 amendments of the Southern Arizona Water Rights Settlement Act aimed at resolving Tohono O'odham water right claims.

Legal Incentives to Use Reclaimed Water

A major impetus for water reuse is found in groundwater law. The 1980 Groundwater Management Act set up a framework for regulation, conservation, and planning in Active Management Areas, where groundwater was being mined to support growing populations and agriculture. The law and the programs developed to implement it required a shift toward renewable water sources such as the Central Arizona Project and effluent. Effluent is a renewable resource because it is generated continuously over time.

In the Phoenix and Tucson Active Management Areas where the act set the goal that groundwater withdrawal should be matched by natural and artificial recharge of the aquifer by 2025, reclaiming water provides an opportunity to both cut groundwater use and augment aquifer recharge, thus decreasing the gap between withdrawal and recharge. Today, Tucson and Phoenix-area municipalities lead the state in reclaimed water use. About 5 percent of the Phoenix AMA's total water demand and about 3 percent of the Tucson AMA's is met by reclaimed water.

Several other components of the law provide incentives for water reuse. Municipal conservation provisions developed in AMA plans established water use reduction targets for municipal water providers in terms of "gallons per capita per day." For water providers subject to these targets, reclaimed water is excluded from the GPCD calculations. The Assured Water Supply rules, which came into effect in 1995, made new development contingent on conformance with water management goals. Developers in AMAs who commit the proposed development to water reuse for ornamental water features, golf courses, or other irrigated landscaping demonstrate availability of a renewable water resource to support the development.

Incorporating reclaimed water systems into their plans can give a private water company a competitive edge. In water scarce areas, water supply plans that include reuse of water are favored by the Arizona Corporation Commission. A private water supplier must obtain a Certificate of Convenience and Necessity from the ACC before it can begin to serve water within a specified service area. In recent cases, a majority of commissioners have voiced their view that new subdivisions should be served by an integrated water and wastewater company to better achieve economies of scale, encourage conservation efforts and facilitate water reuse.

This was the issue in a recent ACC action when competing water utilities, the Arizona Water Company an independent water utility, and Woodruff Water and Sewer Companies, applied to serve a 3,200 acre parcel called Sandia in a fast growing area of Pinal County. The ACC awarded the CC&N to WWSC, in part because the utility would use reclaimed water generated from its planned wastewater treatment facility for the proposed golf course. The utility testified that its integrated approach to wastewater and water was "strategic" to its ability to facilitate and oversee a 20-year build out of the development, and that it would allow it to implement a water reuse program said to be "essential" to the project.

Potable Use of Reclaimed Water

Whatever the uses of reclaimed water, whether now in effect or proposed, none have attracted more attention than its potable use. The topic has garnered attention since Arizona first began reclaiming large amounts of water in the 1980s. While reclaiming water is a popular policy goal, the idea of potable reuse can provoke strong negative reactions from members of the public.

Tracy Williams, a member of Sustainable Tucson and a water activist in Arizona, says that potable reuse would be a mistake because we simply don't know enough about it. "There's a disconnect between science and policy," Williams says. "And it's better to err on the side of the precautionary principle.... There are a lot of levels that we still need to know about."

Scarcity, though, keeps potable reuse at the forefront of discussions about water recycling, and opposition is far from universal. A recent telephone survey of Arizona residents carried out by the Social Research Laboratory at Northern Arizona University found, "if reclaimed water was treated to higher standards and pharmaceuticals and other contaminants were removed," 30 to 45 percent of respondents would support its use for cooking and drinking.

Those favoring potable reuse say that wastewater technologies have developed to the point that recycled water can surpass the standards for drinking water. Further they point out that reclaimed water is a reliable, renewable source that is underutilized.

Cities in several southwestern states, including Arizona, Texas and Colorado use reclaimed water for municipal purposes and are considering potable reuse. Indirect potable

Arroyo Author Moves On

Claire Landowski, the first recipient of the Montgomery & Associates Summer Writing Internship at the WRRC in the summer of 2008, will be graduating with a degree in Geosciences in May. In the fall she will be heading to the University of Wyoming for graduate studies in Glaciology. Claire is enthusiastic about ice and looking forward to working on a project in Greenland to study the water beneath that country's massive glaciers.

The Summer Writing Internship at the WRRC is supported by Montgomery & Associates, Water Resource Consultants.

reuse has already been adopted by a few jurisdictions in the West. Indirect potable reuse involves advanced treatment and recharge of the treated water underground where it mixes with native groundwater before it is pumped and blended with other supplies for delivery to potable water customers.

California has begun to employ indirect potable reuse to meet municipal demand on a large scale, overcoming substantial early public opposition. Since January of 2008, the Orange County Sanitation District and the Orange County Water District have operated the Groundwater Replenishment System, which sends reclaimed water treated at the Fountain Valley Wastewater Treatment Plant to Anaheim, where about half enters spreading basins and percolates into the aquifer. Wells nearby pump water from the aquifer and send it to Orange County for municipal use. The rest is injected into the aquifer along the coast to prevent seawater encroachment.

Trenching to bring reclaimed water service to new commercial development in Flagstaff. Source: Aspen Sawmill Project.

Treatment for wastewater in the Orange County project is slightly more expensive than the current cost of water delivery from Northern California sources. As drought and other factors affect the cost and reliability of deliveries from Northern California, the advantages of the Groundwater Replenishment System water will increase. The local alternative—desalination of seawater—is considerably more expensive.

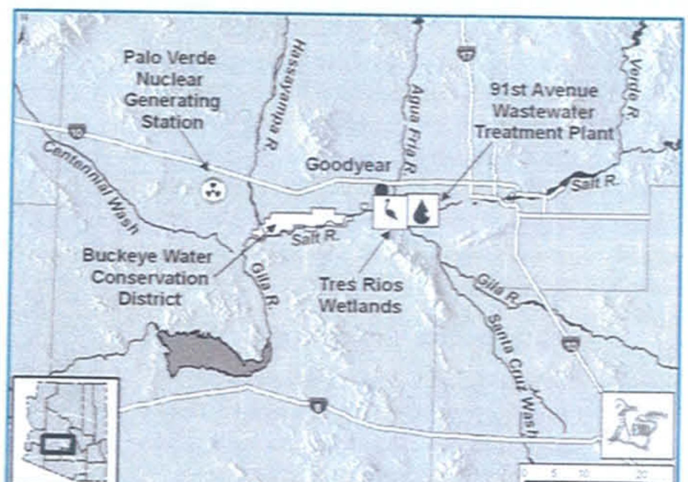
Costs Restrict Reclaimed Water Use

Considering its many advantages and its potential as an expanding water source, why is it that wastewater treatment plants still dispose of so much of the water they collect and treat rather than reusing it? Cost is a primary factor accounting for the failure to recycle more water. Treatment costs can be substantial, but even greater costs are associated with distribution systems.

Because water quality laws forbid distribution of reclaimed water through the potable water distribution system, a completely separate set of pipes is needed to take reclaimed water from its polishing facility to its point of use. Capital and operations costs for a separate reclaimed water system make reclaimed water expensive to distribute. This is especially true in established urban areas that were built up when effluent was still considered a nuisance.

In those times, efficiencies of scale favored the building of large regional collector systems feeding large treatment plants. Collector systems operated by gravity to bring wastewater to plants built downhill from most of the population of the region. In order to serve the population center, a treatment plant would have to pump reclaimed water uphill through a separate system of pipes. This would be a costly enterprise.

For this reason, established municipal wastewater treatment facilities tend to look for nearby or down slope, large-scale users for their effluent and reclaimed water. Phoenix's 91st Ave. Wastewater Treatment Plant is a good example. As of 2007, all of the water generated by the 91st Avenue plant in the summer months, about 120 million gallons per day, is reused by the Palo Verde facility, Tres Rios Ecosystem Restoration Project and Buckeye Water Conservation and Drainage District (see map).



Treated wastewater from Phoenix's 91st Avenue Treatment Plant travels west-southwest to large volume users. Source: Arizona NEMO.

Tucson Water's Reclaimed Water System is an exception. In 2008, it served 12,128 acre-feet of reclaimed water within its service area which was approximately 40 percent of the City's annual effluent entitlement in that year. This recycled water is conveyed through more than 160 miles of pipe to almost 950 sites including 18 golf courses; 51 parks; 62 schools, and more than 700 single family homes. As expansion of the existing system continues, Tucson Water's planners have to consider where it is most appropriate to ensure that the capital investment is cost-effective."

Residential Use of Reclaimed Water

At this point in time, supplying reclaimed water to individual homeowners is an idea with more potential than actual application. Reclaimed water provided to a private residence could be used to water landscapes and flush toilets. This would result in a savings of about 40 to 60 percent of domestic potable water supplies, a significant achievement.

Whatever might be done along this line would have to be done according to regulations. Arizona's reclaimed water program restricts the use of even A+ water to prevent accidental ingestion or inhalation. Accordingly, using reclaimed water in swimming pools or for most uses inside the home is prohibited.

Flushing toilets inside private homes is a permitted use, but local plumbing codes, which usually adopt national standards, require any pipe bringing water into a home to carry only potable water. In addition, the code specifies methods for ensuring that wastewater will never mix with potable water. Some communities have adopted ordinances that permit or even encourage the use of reclaimed water to flush toilets, but a separate set of pipes is required.

Tucson Water supplies reclaimed water to hundreds of residences in the city. Typically these homes use a lot of water for landscape irrigation and, most importantly, are located close to an existing reclaimed water main. Although it is City policy to deliver to any site that meets State and City requirements for reclaimed water use, new customers must be willing to pay for extension of the reclaimed water delivery system as well as their own separate irrigation systems.

On the other hand, problems facing water utilities in built up areas do not prevent developers of planned communities from using reclaimed water at private residences. Global Water, a private water utility located in Phoenix, is championing the development of communities with "purple pipes," a system that brings reclaimed water back to individual homes for exterior use.

Global Water is actively promoting changes in the way we think about residential water and wastewater systems. Graham Symmonds, Global Water chief technical officer says, "Our philosophy is to supply the right water for the right use." In his opinion, the right water for some domestic uses is reclaimed water.

Treating all water that enters a house to potable standards is overkill. Cost and potable water savings would result if reclaimed water could be used for those domestic activities not needing potable water. The challenge is to provide the reclaimed water directly to residents in a cost-effective manner without compromising health and safety.

Regionalization is the strategy that Global Water has adopted to accomplish this goal. The utility's planning is based on townships of 36 square miles, with each planning area having a water reclamation facility with the capacity to treat 10 to 12 million gallons per day. The wastewater can be collected, treated and distributed without extensive pumping because the water is not pumped more than a few miles.

Global Water built its Maricopa facility with regionalization in mind. The local wastewater treatment plant processes about 2.2 million gallons per day to distribute through one leg of a dual distribution system for use in common area landscaping. The dual system includes pressurized mains for potable and recycled water.

The utility's next step is to deliver reclaimed water directly to houses for use in toilet flushing and residential landscape irrigation. Global Water planned such a system, but development is currently on hold due to the severe housing slump.

Large centralized wastewater treatment plants are still being planned, but according to Symmonds, the decentralized approach is what the future holds for reclaimed water use. He says, "I think the days of those monster 200-or 300-million gallon treatment facilities are numbered. Their costs are pretty high in terms of construction and infrastructure."

This contention is one of the issues a team of University of Arizona researchers will be examining under a new grant from the National Science Foundation. The UA team identified water and wastewater as two infrastructures that could be integrated into a single system to be more sustainable and resilient than if operated separately. Principal investigator Kevin Lansey, from the Civil Engineering and Engineering Mechanics Department, said, "Our goal is to try to integrate them and the integration point is through dual water supply and decentralized wastewater treatment."

Two situations are being examined: a clean-slate approach, developing a system from scratch and a retrofit, changing an existing system to adapt it to reclaimed water use. The former strategy is being worked out with Global Water. Partners in the latter approach are the City of Tucson and Pima County who are confronting the need to supply water and wastewater services to developments in the far East side of the city.

UA's Water Quality Center Takes Varied Research Paths

Research at the University of Arizona's Water Quality Center got a boost recently with a National Science Foundation five-year $1.24 million grant. With the funding, the UA center in partnership with Arizona State University and Temple University will be members of the new NSF-funded Water and Environmental Technology Center or WET. The new WET Center will enable the WQC to continue funding the Water Village, a state-of-the-art intermediate field-scale testing facility that is focusing on treatment and distribution of water and wastewater.

Work currently being done at the Water Village is mostly concerned with potable water quality but has down-the-line implications to reclaimed water. WQC director Ian Pepper says the research will provide payoffs in work currently being done as part of a collaborative effort involving the WQC and several UA departments (see right column this page). Pepper says, "Out of that collaboration...we started to focus more and more on integrated water and wastewater treatment and distribution."

The Water Village is a lab where actual real-world work can be done. It consists of a cluster of houses located on the grounds of the UA's Environmental Research Lab. From the outside the houses appear conventional and unremarkable; inside, however, the houses are equipped to serve the needs of water researchers.

A sensing component is set up in one house to monitor for chemical and biological contaminants between two points in the system. Another house, called the network distribution lab, has equipment that can track the dispersion and transport of contaminants. Pepper calls a third building "the final line of defense between the consumer and the contaminated water." Here point-of-use technology is tested that takes out contaminants at the tap. Work going on in another building focuses on low-energy, innovative methods of wastewater treatment. Efforts are underway to devote yet another building to a program providing education and outreach on water reuse.

Regulators are already beginning to see the advantages of integrated systems. The Arizona Corporation Commission, which approves the water rates of private water utilities, has signaled that it will allow companies to recover the costs of laying purple pipes in new developments. A majority of ACC members agree that planning new communities with a purple pipe system is a prudent approach, because it will save water customers money over the long term. Reusing water saves potable supplies, extending the life of existing supplies and reducing the need to find new and probably much more expensive supplies in the future. It also puts in place a distribution system that would likely be much more expensive to build once houses, roads and other infrastructure have been constructed.

Recharge of Reclaimed Water

Another large and growing use for reclaimed water is artificial recharge. Recharge of effluent is specifically permitted by recharge statutes, and many recharge projects use treated wastewater. Through its recharge program, ADWR has permitted 59 underground storage facilities and 20 groundwater savings facilities. More than 7 million acre-feet of water has been stored in permitted facilities, of which perhaps 10 percent is effluent. All effluent recharge projects must obtain Aquifer Protection Permits from ADEQ, specifying water quality and monitoring standards and the use of the best available technology to prevent discharge of pollutants.

Effluent recharge projects serve many purposes. They save water in periods of surplus for use in the future when supplies may not be as plentiful. Advocates maintain that the security recharge provides against shortages during drought make it one of the most valuable uses of reclaimed water. In addition, recharge can provide treatment, improving the quality of the water that is later pumped for use, and allow water to replenish the aquifer in one place in exchange for water pumped elsewhere.

Supplies of reclaimed water are more plentiful during the winter months when the state is host to winter visitors or "snowbirds," who come to Arizona, among other reasons, to play golf. However, turf and landscaping need much less irrigation during the mild winter months. Recharge of reclaimed water stores surplus supplies in the winter for summer use. In this way, the advantages of winter visitors persist after their departure.

Reclaimed water irrigates a playing field in Himmel Park, Tucson. Source: Joe Gelt.

Certain provisions in Arizona's Groundwater Management Code make recharge of reclaimed water especially attractive by creating a system of portable water credits and a potential source of revenue. After passage of the Underground Storage and Recovery Act in 1986, groundwater law permitted the accrual, use and trading of water credits, so-called "paper water." Water credit accounts are administered by the Arizona Department of Water Resources.

Effluent credits are accrued when reclaimed water is recharged according to the requirements of the groundwater code's recharge program. When effluent is stored in a permitted recharge facility, the storing entity receives credits for 50 percent or 100 percent of the water stored, depending on the type of recharge facility. Credits—"paper water"—may be recovered as "wet water." Generally, credits may be recovered from anywhere within the same active management area. Although the credit owner may be pumping native groundwater, it is counted as recovered effluent storage. To protect the aquifer, recovery is limited by water table decline criteria.

The Town of Prescott Valley, in the Prescott Active Management Area, took advantage of the opportunity provided by effluent recharge credits to raise funds for a major water supply project. In October 2007, they held an auction that attracted both local and out-of-state bidders. The winning bid for 2,724 acre-feet of effluent credits will yield more than $67 million over the term of the agreement. By the terms of the agreement, the credits may be used or sold, but any use must be within the town limits.

Reclaimed Water Goes Green

Reclaimed water earns its reputation as a hard-working, versatile resource by irrigating agricultural lands and serving industrial purposes. It provides irrigation water for the grass and other features that make golf courses, parks and neighborhood streetscapes into desert oases. It is the resource that fills out the "water portfolios" of cities, towns and emerging population centers. It recharges overtaxed aquifers and contributes to settling long-standing disputes over water.

Yet there is another side to the resource, what would today be called a "green side"—its environmental application. As Arizona's rivers were tapped to support agricultural, industrial and urban development, the ecosystems that depended on streamflow diminished and disappeared. Many projects have sprung up along these rivers to restore and enhance the riverside environment (see *Arroyo* 2008), and quite a few of these rely on reclaimed water. Tres Rios Ecosystem Restoration and Flood Control Project, for example, was constructed to improve and enhance a 7-mile long, 1500 acre section of the Salt and Gila Rivers in southwestern Phoenix. The water for the Tres Rios Project, about 25,000 acre-feet per year, is highly treated effluent from the 91st Avenue treatment plant.

In some places, however, life has sprung up without planning or projects, where cities dispose of wastewater. Reliable flow in the Santa Cruz River, which once flowed perennially in some stretches, now occurs only where treatment facilities discharge wastewater into the channel. The Upper Santa Cruz River is watered by the Nogales International Wastewater Treatment Plant in Santa Cruz County, which processes sewage from Nogales, Arizona and Nogales, Sonora. An average of about of 15 million gallons per day, or about 17,000 acre-feet per year, is discharged into the river and flows north over shallow alluvium supporting a 12-mile riparian corridor. Further down river the Santa Cruz again benefits from a release of treated wastewater. The Roger and Ina Road wastewater treatment plants release 50,000 to 60,000 acre-feet of effluent per year into the Santa Cruz River north of Tucson.

Swathes of green in an arid environment, the river segments depending on these discharges rely on an uncertain supply. The effluent flows have created valuable environmental benefits: willow and cottonwood line the banks of the river, their branches filled with birds' nests. Although this natural abundance attracts tourists, provides recreation opportunities to residents, and increases real estate values, there is concern that as the demand for reclaimed water increases, uses associated with development could trump environmental uses. Treated wastewater will be considered too valuable to leave in the river.

Reclaimed Water Treatment

Reclaimed water's treatment and use are twin concerns: the type and level of treatment determine appropriate reuse. Reclaimed water undergoes various types of treatment from natural processes to the highly engineered processes of a wastewater treatment plant.

Wastewater Treatment Plant

Treatment of wastewater has improved significantly in the United States since 1972, when the Clean Water Act came into effect. Discharge of raw sewage, once fairly common, has become a rare occurrence. Treatment technologies have advanced and new methods with demonstrated effectiveness have become established practices.

Commonly there are three levels of treatment: primary, secondary and tertiary. Primary treatment is the first step in the process. It removes solids, mainly with screens and settling basins. After sludge has settled out, the wastewater moves to secondary treatment.

Secondary treatment removes most suspended solids, some dissolved solids and organic matter. The treatment train involves biological and/or chemical activity to transform undesirable compounds into more benign forms. The effluent is then disinfected with chlorine or other disinfectant to kill potentially harmful microorganisms and discharged, unless additional treatment is warranted. When the effluent is not intended for reuse, it is usually discharged into a nearby waterway or pond.

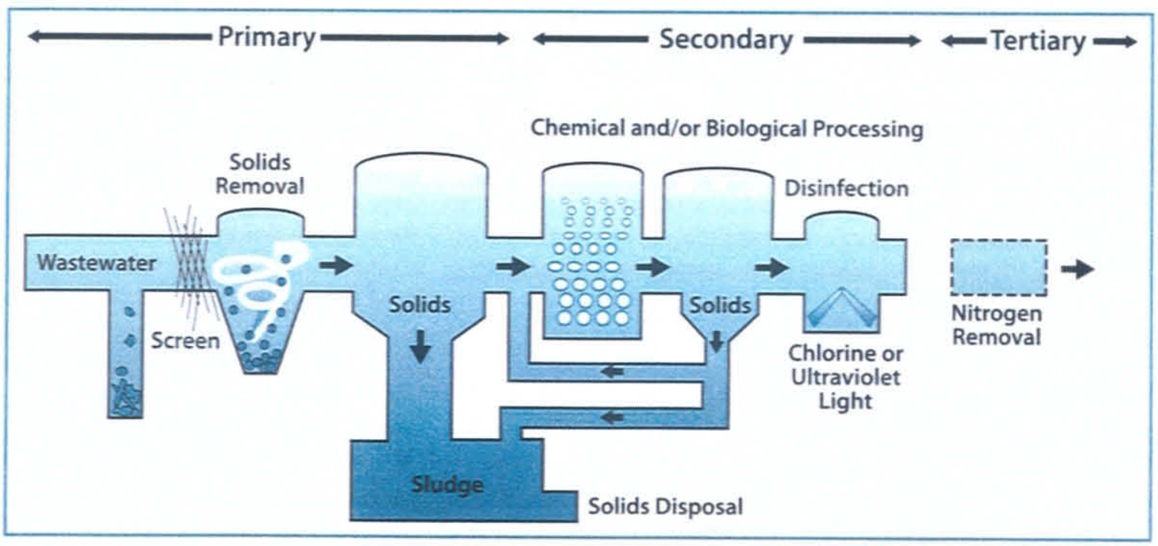
Secondary effluent must undergo additional treatment to meet requirements for most allowed uses of reclaimed water. Tertiary treatment includes removal of inorganics such as phosphorus, nitrogen or metals, usually by filtration. Further processing, such as ultra violet treatment or chlorine disinfection, may be used to kill microbial pathogens before discharge.

The Clean Water Act of 1972 required that all wastewater be put through primary and secondary treatment processes before it could be discharged to a waterway, and water quality standards for the receiving waterway may necessitate additional treatment. Arizona's Aquifer Protection Permit program, initiated in 1987, extended treatment requirements to any discharge to groundwater. All aquifers in Arizona are protected as drinking water aquifers, with aquifer water quality standards set at national primary drinking water maximum contaminant levels. Under the APP program, new or expanded wastewater treatment plants must upgrade beyond secondary standards to include denitrification, thereby producing only A+ or B+ water.

Many water and wastewater managers are reaching the conclusion that the standards for wastewater treatment in Arizona are now so high that reusing the water has almost become a necessity. Utilities can no longer afford to spend the considerable sums needed for advanced treatment just to throw the water away. This reasoning has prompted a number of reuse arrangements, including a unique project in Pinal County for reclaiming water from mine dewatering for agricultural irrigation (see inset p. 10).

Scottsdale provides an example of the highly complex process involved in treating reclaimed water for injection into the aquifer to replenish groundwater. Well-injection recharge requires water treated to drinking water standards and conditioned to be compatible with native groundwater. An article by Penelope B. Grenoble in the January–February edition of *Water Efficiency* describes the process: "Scottsdale's effluent treatment chain includes: 400-micrometer strainers, followed by ammonia to eliminate free chlorine, which is followed by microfiltration and an antiscalant. Next comes pH adjustment using sulfuric acid, then 20 micrometer cartridge filters, a thin film composite polyamide RO in a three-stage configuration of 24:10:5 with a recovery rate of 85%, degasifier towers for reduction of carbon dioxide, and, finally, lime feed for RO permeate stabilization."

Using this treatment method, Scottsdale is producing potable quality water at its



Typical reclaimed water treatment.

When Treatment and Use Is Not Reuse

Not all reclaimed water is reused water. By definition, water reuse means water used in some fashion is treated and used again. Poor quality water occurring naturally or resulting from careless or illegal practices can be treated for use. A description of an innovative project that treats and delivers mining water for irrigation should clarify this distinction.

Water that has been slowly filling up an abandoned mine shaft near Superior, Arizona, contains a concentrated stew of heavy metals and salts leached from the rock. Before reopening the mine, Resolution Copper must pump the water out and get rid of it. After concluding that they would have problems obtaining the necessary permits from the Arizona Department of Environmental Quality to discharge the water into Queen Creek, the mining company came up with an another plan. Their solution is to treat the water to remove the metals and most of the salts, and pipe it to the New Magma Irrigation District. The irrigation district will dilute the treated mine water with Central Arizona Project water at a 1 to 10 ratio, the ratio scientists believe will result in no adverse effects. "This [project] helps the mine get rid of its contaminated water and it helps New Magma extend its water supply," says Bill Baker, the attorney for New Magma who negotiated the contract with Resolution Copper and the UA.

University of Arizona researchers will operate as a consultant on the project, monitoring the quality of the water both before and after mixing, and tracking the quality of the soil that receives the mine's water. The supply pipeline will be shut down immediately if a water quality problem is detected. Dr. Jeff Silvertooth, the head of the Soil, Water and Environmental Science department at UA, will oversee the monitoring side of the project. According to Silvertooth, at first the growers in the New Magma district worried that the mixed water wouldn't be of high enough quality to use safely. The UA's initial investigation of the best dilution ratio and continuing presence as a quality monitor was what ultimately convinced local water users to support the project.

Although not technically a water-reuse project, the mining operation does address the same goals, namely making use of nuisance water. Treating brackish or saline groundwater for use is another example of making use of nuisance water. The abundance of this low-quality water supply near Buckeye, Arizona, makes the town an attractive place to build a desalination plant, which has been talked about by state organizations, particularly the Central Arizona Project. The Town of Goodyear already desalinates brackish groundwater for municipal use.

Water Campus. After recharge the treated water is allowed to linger underground and co-mingle with native groundwater and recharged CAP water. Then it is pumped from wells that are part of the city's water supply system, thus making its way eventually and indirectly to consumers' taps.

Nature at Work—Soil Aquifer Treatment

Few effluent recharge projects in Arizona go to the lengths that Scottsdale does to treat water before recharge. Arizona's typical effluent recharge projects use spreading basins rather than aquifer injection. This allows operators to rely on Soil Aquifer Treatment to reduce contaminants that remain after treatment. The physical, chemical and biological treatment that cleans water as it seeps through soil—SAT—can be an important benefit of recharge.

SAT is sometimes used as an additional treatment for reclaimed water because research has shown that near surface sediments can act as filters, improving the water's quality as it percolates down to the aquifer. Like other treatment methods, SAT is more effective for some water-quality issues than for others (see inset on p. 11).

Some trace organic compounds will move out of water and attach themselves to the surface of soil particles as the water moves through the sediment, leaving only a higher-quality water to enter the aquifer. For example, research at the University of Arizona by David Quanrud and others has shown that the activity of the hormone estrogen is greatly reduced during soil-aquifer treatment, and that only about 1 meter of biochemically active sediment is needed to reduce hormone presence by 90 percent. Quanrud estimates that after the estrogenic compounds attach to soil particles, it takes about three months for them to degrade and disappear. Therefore, active estrogenic compounds should not be present at all if the effluent spends more than a few months underground.

Nature at Work—Constructed Wetlands

Another treatment method that takes advantage of natural processes is passage through wetlands. Duplicating the processes occurring in natural wetlands, constructed wetlands are complex, integrated systems in which water, plants, animals, microorganisms and the environment—sun, soil, air—interact to improve water quality. Wetlands are efficient at removing contaminants from wastewater, including BOD (Biological Oxygen Demand), suspended solids, organic compounds like phosphorus and nitrogen, hydrocarbons, metals and even some pharmaceutical compounds.

Water is treated by moving slowly through a basin, maximizing the time that wastewater is in contact with the soil and plant surfaces within the wetlands. Microorganisms in the soil and water break down pollutants, and suspended solids settle to the bottom, leaving higher-quality water to flow out of the basin.

Many Arizona cities have effluent-dependent wetlands constructed in conjunction with a wastewater treatment plant. Show Low was first in the state to develop artificial wetlands to treat wastewater. Show Low's need for wetlands treatment became evident in the mid 1970s, when effluent dumped into Show Low Creek caused algae blooms and fish kills downstream in Fool Hollow Lake. In 1977, the Apache-Sitgreaves National Forest, Arizona Game and Fish Department, City of Show Low, and Show Low Sanitary District formed a partnership that built Pintail and South Lake Marshes. In 1985 Redhead Marsh was added. The facility is now a 200-acre wetlands treatment system that doubles as a nesting ground for waterfowl.

Two of the best-known constructed wetlands in the state, the celebrity wetlands, are Sweetwater Wetlands in Tucson and Tres Rios Demonstration Wetlands in Phoenix, both located within major metropolitan areas. Both of these facilities are relatively small; Sweetwater consists of about 12 acres and has no plans for expansion. Tres Rios also is small at 14 acres, but construction is underway for a 220-acre wetlands adjacent to the current one.

In Tucson, the Sweetwater Wetlands were designed to optimize the natural process of nitrification-denitrification that breaks down ammonia into nitrogen gas. Ammonia, common in wastewater from urine, is one of the biggest concerns in wastewater treatment because of its toxicity to aquatic life. The quality of water leaving the wetlands is actually superior to the groundwater beneath it, says Joachim Delgado, Tucson Water's Public Information Specialist.

About 125 miles to the northwest, the Tres Rios Demonstration Wetlands consists of two separate sites that together receive between 2 and 3 million gallons of reclaimed water each day. Unlike other constructed wetlands, the purpose of the Tres Rios wetlands is not to continue to clean the water leaving the plant. Strictly speaking, the plant's effluent water is well above standards for wastewater discharge. Yet, at the point where the treatment plant discharges its regular, non-wetlands-treated effluent into the river, only the most hardy fish species—carp and tilapia—live in the water.

In a sense this effluent is too clean. According to Ron Elkins, of City of Phoenix Water Services Department and construction project manager, the wetlands speed conditioning of the water to support a healthy ecosystem. Normally, it takes the plant's effluent 6 miles in the river to absorb enough nutrients so that it can support a rich ecosystem. "In the wetlands, we can achieve that in about 300 feet," says Elkins.

The wetlands is being expanded after its 13-year trial run. September 2008 marked the groundbreaking for the construction of a full, 220-acre wetlands about 100 yards downstream from the current one. The new project, which will be called the Freewater Wetlands, is expected to be completed in 14 months.

Regulation-defying Contaminants

As regulators are well aware, water regulations can lag behind the introduction and use of substances that are potentially injurious to human health or the environment; thus simply meeting regulatory standards does not guarantee safety.

Recently, much attention has been given to a group of compounds commonly found in pharmaceuticals and personal care products that may be endocrine disruptors. The EPA has identified about 87,000 compounds as potential endocrine disruptors, EDCs, and it is likely that many of them occur in wastewater, though research on their prevalence in the U.S. is still fledgling. Currently, there are no regulations for acceptable concentrations of these compounds in wastewater because only relatively recently have they been identified and linked to health effects in ecosystems and humans.

Another set of compounds of emerging concern are polybrominated diphenyl ethers, also known as PBDEs. These compounds were once widely used as flame retardants for fabric and plastics, and now are often present in wastewater at detectable concentrations. Despite their ubiquity, human health effects of PBDEs, if any, are uncertain because they have not yet been studied. Animals exposed to PDBE before and after birth have been observed to have brain development, learning, and memory problems.

Many of these newly emerging contaminants are removed effectively by wastewater treatment plants, but some seem to be resistant to traditional technologies. Research has shown that soil aquifer treatment (see Treatment p. 10) is effective in removing the hormone estrogen, an EDC. Research on the effectiveness of SAT for removing PBDE compounds is less reassuring. PBDEs are leached from water during SAT, but unlike estrogens, they are not destroyed. Instead, they are conserved in soil and may accumulate in near-surface sediments.

The more advanced treatment technologies appear to be more effective in removing wastewater contaminants, including EDCs and PBDEs. For example, adding denitrification to wastewater treatment processes has the added bonus of removing estrogens. In fact, technologies exist for producing ultra-pure water, but they are prohibitively expensive for most uses. The question facing communities is ultimately to find an acceptable balance of risk and cost—how much money to spend for what level of treatment.

Graywater

Purple pipes: a dual piping system is used in the City of Maricopa to keep reclaimed water and potable water separate. Source: Channah Rock.

Advanced treatment in wastewater treatment facilities, wetlands, or recharge projects is not required, however, when conservation-minded homeowners want to reuse water to irrigate the trees, shrubs and other plants around their homes. Water reuse can begin at home, by diverting water drained from bathtubs, showers, bathroom sinks and washing machines to use in the yard. Wastewater from these sources, called graywater, is still usable, containing small amounts of detergents or ordinary dirt. Water from kitchen sinks, dishwashers and toilets is called blackwater and is barred from home reuse.

The ADEQ is responsible for permitting graywater use. The agency does not require a permit for homeowners producing less than 400 gallons a day to collect and use graywater, but homeowners or businesses using more than that must get a permit. A dual plumbing system is necessary to use graywater, which costs from $500 to $1000 depending on the complexity of the system. Regulations are not onerous; however they do require that graywater pipes be labeled so they can be distinguished from drinking water pipes and that all storage tanks be covered and sealed to protect against rodents and mosquitoes. If a backup occurs in the system, the graywater must be disposed of into a regular drain.

In addition, the ADEQ has developed guidelines for graywater use. They state that people should avoid contact with the water, should not allow it to run off the property, should not use it in any form of spray irrigation or to irrigate food plants except citrus and nut trees. Homeowners should be careful that chemicals like antifreeze, mothballs, solvents or oil do not enter the system. ADEQ also recommend the use of a simple filtration system to minimize plugging.

Despite these rules, public officials are concerned about the widespread use of home graywater systems. Some of their concerns focus on public health. Every time a homeowner ignores the rules, through carelessness or ignorance—a baby's diaper rinsed in the bathroom sink or household solvent poured down a drain—poten-

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tially harmful substances get into the system and from there into the environment.

Other concerns focus on potential effects on reclaimed water systems. It may seem ironic that there is tension between conservation strategies like graywater use and increasing reclaimed water use, both being strategies to extend current water supplies. But, residential graywater use will lead to reduction in the amount of reclaimed water that can be produced and redistributed. In addition, because it reduces the amount of water flowing back to the wastewater treatment plant, there is a risk of clogged sewer pipes where there is not enough liquid water to carry the solids to the treatment plant.

Needed: an Informed Public

With such a complex and multi-faceted issue, it is not surprising that there are differences of opinion about water reuse. There is strong public support for water recycling as a general policy, but the devil is in the details. Some aspects of the issue, such as the potential for potable reuse, are emotionally charged, engendering controversy and public debate. Citizens have been sufficiently worked up to adopt dueling slogans, with those fretting about potable use decrying "toilet to tap" and those in favor of expanded reclaimed water use proclaiming "showers for flowers."

The debate is bringing to the forefront a challenge that water managers have been aware of: the need to educate and inform the public about critical water issues. Whether the issue is conservation, water quality, water pricing or, as in this case, the use of reclaimed water, most water officials realize that the involvement of an informed public can be a deciding factor in the successful implementation of a needed policy.

Madeline Kiser, a Tucson citizen active in the community, says that the problem with reclaimed water use, particularly potable reuse, is that the public doesn't know enough about it. "It's hard to be a layperson in this debate," Kiser says. "I don't think people really know what we are choosing. We need transparency and clarity and debate."

The Director for Water Reuse at HDR Engineering, Guy Carpenter, seconds this sentiment: "As scientists, we can throw all kinds of technologies at water solutions, but unless the public accepts the solution, history has shown that it won't happen. A well informed public ... is key," says Carpenter.

Scientists and professionals in Arizona and throughout the West are working to produce the information needed for informed decision making. Some of the many research activities on-going at the University of Arizona were mentioned in this *Arroyo*. Continued research will be needed to provide information to support decisions, and continued outreach is needed to get the information to the people who need it.

In the previously cited survey, researchers found that although almost two-thirds of Arizona residents have concerns about reclaimed water, approximately 80 percent of respondents said that these concerns can be alleviated by providing "better information about reclaimed water." Results of the survey, a component of an Arizona Water Institute funded project led by Channah Rock at the University of Arizona, Department of Soil, Water and Environmental Science, highlight issues of risk and trust that motivate public attitudes to reclaimed water. Addressing these issues will encourage a more constructive public dialog on water reuse.

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