Classification of each sub-category for adopting water recycling technology

1. Overview

The ability to reuse water, regardless of whether the intent is to augment water supplies or manage nutrients in treated effluent, has positive benefits that are also the key motivators for implementing water reuse projects. These benefits include improved agricultural production; reduced energy consumption associated with production, treatment, and distribution of water; and significant environmental benefits, such as reduced nutrient loads to receiving waters due to reuse of the treated wastewater.

While the increased use of reclaimed water typically poses greater financial, technical, and institutional challenges than traditional sources, a range of treatment options are available such that any level of water quality can be achieved depending upon the use of the reclaimed water.

This concept is represented graphically in Figure 1-3, which illustrates that water treatment technologies (combined with disinfection) offer a ladder of increasing water quality, and choosing the right level of treatment should be dictated by the end application of the reclaimed water for achieving economic efficiency and environmental sustainability.

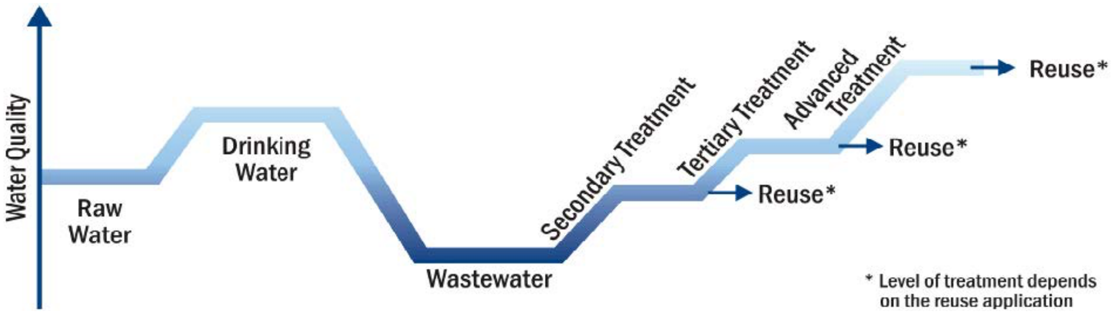

Figure 1. Treatment technologies are available to achieve any desired level of water quality (Guideline for Water Reuse, EPA 2012)

2. Type of Application for water reuse

There are several major types of application for water reuse, including agricultural, industrial, environmental, recreational, and potable reuse, etc.

2.1 Urban Reuse

Applications such as recreational field and golf course irrigation, landscape irrigation, and other applications, including fire protection and toilet flushing, are important components of the reclaimed water portfolio of urban reuse. Urban reuse is often divided into applications that are either accessible to the public or have restricted access, in settings where public access is controlled or restricted by physical or institutional barriers, such as fences or temporal access restriction.

In order to maximize the use of potable water in resource-limited systems, communities are working to identify alternatives for minimizing non-potable consumption by supplying reclaimed water for reuse. When used to irrigate residential areas, golf courses, public school yards, and parks, reclaimed water receives treatment and high-level disinfection and is not considered a threat to public health. However, the water quality of reclaimed water differs from that of drinking quality water or rainfall and should be considered when used for irrigation and other industrial reuse applications. Of particular importance are the salts and nutrients in reclaimed water, and special management practices for both end uses may be required depending on the concentrations in the reclaimed water. For example, in some areas where landscaping is irrigated, the salt sensitivity of the irrigated plants should be considered.

In addition to managing water quality, many facilities are required to implement special management practices where reuse is implemented to minimize the potential of cross-connection of water sources.

2.2 Agricultural Reuse

Water availability is central to the success of agricultural enterprises domestically and globally. Farming could not provide food for the world's current populations without adequate irrigation (Kenny et al., 2009). By 2050, rising population and incomes are expected to demand 70 percent more production, compared to 2009 levels.
Agricultural use of reclaimed water has a long history and currently represents a significant percentage of the reclaimed water used in the world. Reclaimed water from municipal and agricultural sources provides many advantages, including:

- The supply of reclaimed water is highly reliable and typically increases with population growth.
- The cost of treating wastewater to secondary (and sometimes even higher) standards is generally lower than the cost of potable water from unconventional water sources
- The option of allocating reclaimed water to irrigation is often the preferred and least expensive management alternative for municipalities
- Reclaimed water is an alternative to supplement and extend freshwater sources for irrigation.
- In many locales, reclaimed water might be the highest quality water available to farmers, and could represent an inexpensive source of fertilizer.

When considering the use of reclaimed water in agriculture, it is important to identify the key constituents of concern for agricultural irrigation. *Plant sensitivity* is generally a function of a plant's tolerance to constituents encountered in the root zone or deposited on the foliage, and reclaimed water tends to have higher concentrations of some of these constituents than the groundwater or surface water sources from which the water supply is drawn. The types and concentrations of constituents in reclaimed water depend on the municipal water supply, the influent waste streams (i.e., domestic and industrial contributions), the amount and composition of infiltration in the wastewater collection system, the treatment processes, and the type of storage facilities. Determining the suitability of a given reclaimed water supply for use as a supply of agricultural irrigation is, in part, site-specific, and agronomic investigations are recommended.
The trace element and nutrients criteria recommended for fine-textured neutral and alkaline soils with high capacities to remove the different pollutant elements are provided in the table below.

Table 1. Recommended water quality criteria for irrigation

Constituent	Maximum Concentration for irrigation (mg/ L)	Remark
Aluminum	5.0	Can cause non productiveness in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity
Arsenic	0.10	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice
Beryllium	0.10	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans
Boron	0.75	Essential to plant growth; sufficient quantities in reclaimed water to correct soil deficiencies. Optimum yields obtained at few-tenths mg/L; toxic to sensitive plants (e.g., citrus) at 1 mg/L. Most grasses are tolerant at 2.0 - 10 mg/L
Cadmium	0.01	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L; conservative limits are recommended
Chromium	0.1	Not generally recognized as an essential element; due to lack of toxicity data, conservative limits are recommended
Cobalt	0.05	Toxic to tomatoes at 0.1 mg/L; tends to be inactivated by neutral and alkaline soils
Copper	0.2	Toxic to a number of plants at 0.1 to 1.0 mg/L
Fluoride	1.0	Inactivated by neutral and alkaline soils
Iron	5.0	Not toxic in aerated soils, but can contribute to soil acidification and loss of phosphorus and molybdenum
Lead	5.0	Can inhibit plant cell growth at very high concentrations
Lithium	2.5	Tolerated by most crops up to 5 mg/L; mobile in soil. Toxic to citrus at low doses—recommended limit is 0.075 mg/L
Manganese	0.2	Toxic to a number of crops at few-tenths to few mg/L in acidic soils
Molybdenum	0.01	Nontoxic to plants; can be toxic to livestock if forage is grown in soils with high molybdenum
Nickel	0.2	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH
Selenium	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of selenium
Tin, Tungsten, and Titanium	-	Excluded by plants; specific tolerance levels unknown
Vanadium	0.1	Toxic to many plants at relatively low concentrations
Zinc	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils

Note: Guideline for Water Reuse, EPA 2012

2.3 Environmental Reuse

Environmental reuse primarily includes the use of reclaimed water to support wetlands and to supplemental stream and river flows. Water conservation and reuse can reduce the demand on aquifers, as can river or stream flow augmentation. River and stream augmentation differs from a surface water discharge in several ways. River or stream flow augmentation may provide an economical method of ensuring water quality, as well as having other benefits. It can minimize the challenge of locating a reservoir site, the additional water can improve the overall water quality of the receiving water body, and it can ameliorate the effect of low flow drought conditions, providing high quality water at the time of test need.

2.4 Industrial Reuse

Traditionally, pulp and paper facilities, textile facilities, and other facilities using reclaimed water for cooling tower purposes, have been the primary industrial users of reclaimed water. Over the past few years, these industries have embraced the use of reclaimed water for purposes ranging from process water, boiler feed water, and cooling tower use to flushing toilets and site irrigation. In addition, these facilities recognize that reclaimed water is a resource that can replace more expensive potable water with no degradation in performance for the intended uses.

2.4.1 Boiler water

The use of reclaimed water for boiler make-up water differs little from the use of conventional potable water—both require extensive pre-treatment. Water quality requirements for boiler make-up water depend on the pressure at which the boiler is operated; in general, higher pressures require higher-quality water.

2.4.2 High Technology water reuse

The use of reclaimed water in high-technology manufacturing, such as the semiconductor industry, is a relatively new practice. Within the semiconductor industry, there are two major processes that use water: microchip manufacturing, which has rarely utilized reclaimed water, and the manufacture of circuit boards. In circuit board manufacturing, water is used primarily for rinse operations; similar to production of boiler feed water, reclaimed water for circuit board manufacturing requires extensive treatment. While only circuit board manufacturing uses reclaimed water in the actual production process, both semiconductor and circuit board manufacturing facilities do use reclaimed water for cooling water and site irrigation.

2.5 Groundwater Recharge

Groundwater recharge to aquifers not used for potable water has been practiced for many years, but has often been viewed as a disposal method for treated wastewater effluent. In addition to providing a method of treated effluent disposal, groundwater recharge of reclaimed water can provide a number of other benefits including

- Recovery of treated water for subsequent reuse or discharge
- Recharge of adjacent surface streams

- Seasonal storage of treated water beneath the site with seasonal recovery for agriculture

In many cases, groundwater can be recharged in a manner that also utilizes the soil or aquifer system where reclaimed water is applied as an additional treatment step to improve the reclaimed water quality.

2.6 Potable Reuse

Water reclamation for non-potable applications is well established with system designs and treatment technologies that are generally well accepted by communities, practitioners, and regulatory authorities. The use of reclaimed water to augment potable water supplies has significant potential for helping to meet future needs, but planned potable water reuse only accounts for a small fraction of the volume of water currently being reused. However, if de facto (or unplanned) water reuse is considered, potable reuse is certainly significant to the nation's current water supply portfolio. The unplanned reuse of wastewater effluent as a water supply is common, with some drinking water treatment plants using waters from which a large fraction originated as wastewater effluent from upstream communities, especially under low-flow conditions.

Several examples of IPR and DPR projects are summarized in Table below to illustrate that this practice occurs worldwide at both very small and very large scales. And there are countless other planned IPR applications, where treated wastewater is deliberately recharged to a groundwater aquifer using rapid infiltration basins or injection wells, or to a drinking water reservoir.

Table 2. Overview of selected planned indirect and direct potable reuse installations worldwide

country	City	Capacity (MGD)	Description of Advanced System for Potable Reuse
Belgium	Wulpen	1.9	Reclaimed water is returned to the aquifer before being reused as a potable water source
India	Bangalore (planned)	36	Reclaimed water will be blended in the reservoir, which is a major drinking water source
Namibia	Windhoek	5.5	Reclaimed water is blended with conventionally-treated surface water for potable reuse
United States	Big Spring, Texas	3	Reclaimed water is blended with raw surface water for potable reuse
United States	Upper Occoquan, Virginia	54	Reclaimed water is blended in the reservoir, which is a major drinking water source
United States	Orange County, California	40	Reclaimed water is returned to the aquifer before being reused as a potable water source
United Kingdom	Langford	10.5	Reclaimed water is returned upstream to a river, which is the potable water source
Singapore	Singapore	122	Reclaimed water is blended in the reservoir, which is a major drinking water source
South Africa	Malahleni	4.2	Reclaimed water from a mine is supplied as drinking water to the municipality

Note: Guideline for Water Reuse, EPA 2012

Implementation of technologies for increasingly higher levels of treatment for many of these IPR projects has led to questions about why reclaimed water would be treated to produce water with higher quality than drinking water standards, and then discharged to an aquifer or lake. This realization has led to new interest in DPR, utilizing the various multiple-barrier treatment technologies. However, even with the numerous successful IPR projects, Windhoek, Namibia, was the first city to implement long-term DPR without use of an environmental buffer. This is an example of the distinction between IPR and DPR:

2.6.1 Indirect Potable Reuse (IPR)

Planned IPR involves a proactive decision by a utility to discharge or encourage discharge of reclaimed water into surface water or groundwater supplies for the specific purpose of augmenting the yield of the supply.
the decision to pursue planned IPR typically involves the following factors.

- Limited availability and yield of alternate sources
- High cost of developing alternate water sources
- Conscious or unconscious public acceptance
- Confidence in, and some level of control over, both advanced reclaimed water treatment processes and water treatment processes

In some cases, the level of reclaimed water treatment required to meet water quality standards is considerable. The incentive to provide additional treatment may be driven by regulations intent on protecting water supplies but in most cases is also linked to benefits to the discharger or community in increasing the yield of water supplies that they depend on either directly or indirectly. While satisfying these four factors may be necessary to pursue IPR, they are not sufficient. Two specific components of these factors typically control the viability of implementation. First, even though existing water supplies may be of limited availability and yield, the means via water rights, permits, and storage contracts must exist to reap the benefits of withdrawing the additional yield of the augmented water supply. Second, public acceptance of IPR is of paramount importance but sometimes takes counterintuitive turns based on the specifics of the project and the local community.

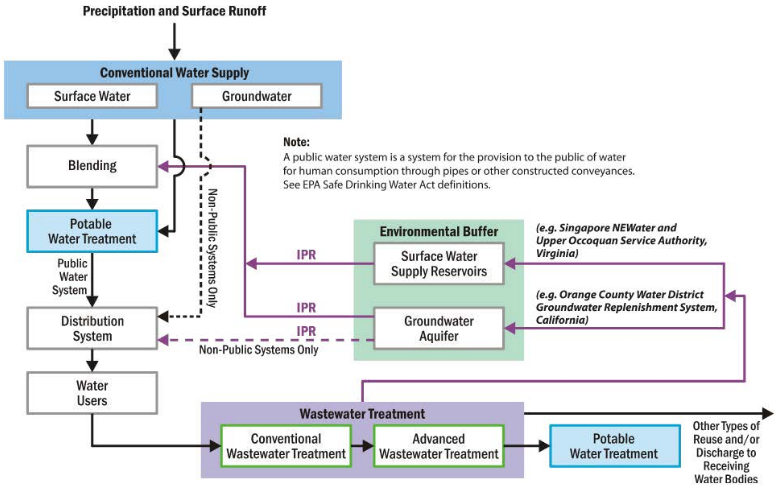

Figure 2. Planned IPR scenarios and examples (Guideline for water reuse, EPA 2012)

2.6.2 Direct Potable Reuse (DPR)

Considering that unplanned reuse is already widely practiced, DPR may be a reasonable option based on significant advances in treatment technology and monitoring methodology in the last decade and health effects data from IPR projects and DPR demonstration facilities. A number of recent publications have focused on identifying the role that DPR will have in the management of water resources in the future (Tchobanoglous et al., 2011; NRC, 2012; Crook, 2010; Leverenz et al., 2011; Schroeder et al., 2012). DPR refers to the introduction of purified water, derived from municipal wastewater after extensive treatment and monitoring to assure that strict water quality requirements are met at all times, directly into a municipal water supply system. The resultant purified water could be blended with source water for further water treatment or could be used in direct pipe-to-pipe blending, providing a significant advantage of utilizing existing water distribution infrastructure.

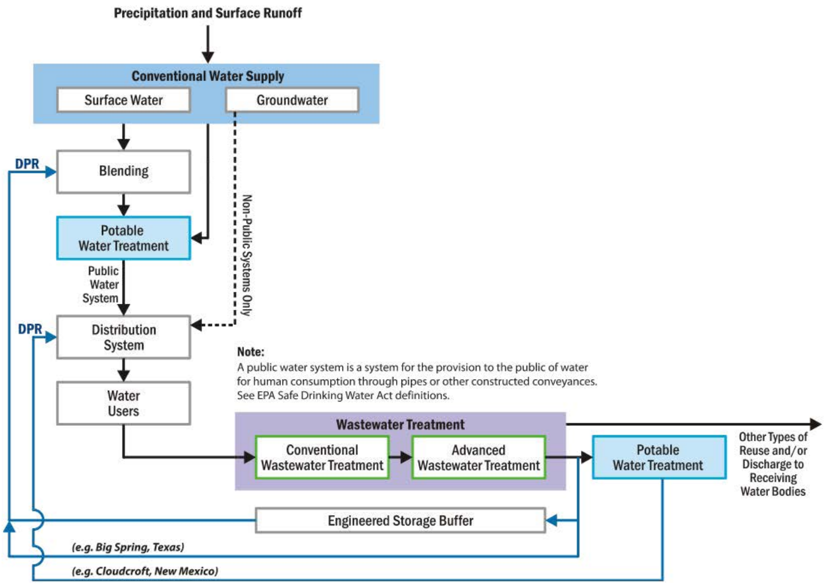

Figure 2. Planned IPR scenarios and examples (Guideline for water reuse, EPA 2012)

In the first option, purified water is first placed in an engineered storage buffer; from there, purified water is blended with the water supply prior to water treatment. In the second option, purified water, without the use of an engineered storage buffer, can be blended back into the distribution system for delivery to water users. An in-depth discussion of implementation of these options is provided by Tchobanoglous et al. (2011) and Levernez et al. (2011), along with the concept and role of the engineered storage buffer, which is a mechanism for detention to provide response time for any off-specification product water.

In many parts of the world, DPR may be the most economical and reliable method of meeting future water supply needs. While DPR is still an emerging practice, it should be evaluated in water management planning, particularly for alternative solutions to meet urban water supply requirements that are energy intensive and ecologically unfavorable. This is consistent with the established engineering practice of selecting the highest quality source water available for drinking water production.

3. Treatment Technology for water reuse

Treatment Level	Increasing Levels of Treatment →			
	Primary	Secondary	Filtration and Disinfection	Advanced
Processes	Sedimentation	Biological oxidation and disinfection	Chemical coagulation, biological or chemical nutrient removal, filtration, and disinfection	Activated carbon, reverse osmosis, advanced oxidation processes, soil aquifer treatment, etc.
End Use	No Uses Recommended	Surface irrigation of orchards and vineyards	Landscape and golf course irrigation	Indirect potable reuse including groundwater recharge of potable aquifer and surface water reservoir augmentation and potable reuse
		Non-food crop irrigation	Toilet flushing	
		Restricted landscape impoundments	Vehicle washing	
		Groundwater recharge of nonpotable aquifer	Food crop irrigation	
		Wetlands, wildlife habitat, stream augmentation	Unrestricted recreational impoundment	
		Industrial cooling processes	Industrial systems	
Human Exposure	Increasing Acceptable Levels of Human Exposure →			
Cost	Increasing Levels of Cost →			