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Multiple Uses of Water: Reclamation and Reuse

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Trends in Efficient Water Use

Inadequate water supply and water quality deterioration represent serious contemporary concerns for many municipalities, industries, and agriculture in various parts of the world. Several factors have contributed to these problems; continued population growth in urban areas, contamination of surface water and groundwater, uneven distributions of water resources, and frequent droughts have forced water agencies to search for new dependable water supply. For more than a quarter of a century, a recurring thesis in environmental and water resources engineering has been that it is feasible to treat wastewater to a high enough quality that it is a resource which could be put to beneficial use rather than wasted. By applying this conviction to responsible engineering, coupled with the vexing problems of increasing water shortages and environmental pollution, a realistic framework has emerged for considering "multiple uses of water" via reclamation and reuse in many parts of the world. The water pollution control efforts in many countries have made treated municipal and industrial wastewater suitable for economical augmentation to the existing water supply, when compared to increasingly expensive and environmentally destructive new water resources development.

Water reclamation and reuse accomplishes two fundamental functions: (1) the treated effluent is used as a water resource for beneficial purposes, and (2) the effluent is kept out of streams, lakes, and beaches; thus, reducing pollution of surface water and groundwater. In this paper, fundamental concepts of multiple uses of water via reclamation and reuse are developed that include categories of water reuse and technological innovations for the safe use of reclaimed water. The article emphasizes the integration of this alternative water supply into water resources planning and the emergence of modern wastewater reclamation and reuse practices from wastewater to reclaimed water to "repurified/new" water through "multiple uses of water" via reclamation and reuse. Water reclamation and reuse have been dubbed as the *greatest challenge of the 21st century* as water supplies remain finite and water demands increase because of escalating populations and per capita consumption. Today, technically proven water reclamation or purification processes exist to provide water of almost any quality desired [1].

Multiple Uses of Water

The foundation of multiple uses of water is built upon three principles: (1) providing reliable treatment of wastewater to meet strict water quality requirements for the intended reuse application, (2) protecting public health, and (3) gaining public acceptance. Whether water reuse is appropriate for a specific locale depends upon careful economic considerations, potential uses for the reclaimed water, and the relative stringency of waste discharge requirements. Public policies can be implemented that promote water conservation, and reclamation and reuse rather than the costly development of additional water resources with considerable environmental expenditures. Through integrated water resources planning, the use of reclaimed water may provide sufficient flexibility to allow a water agency to respond to short-term needs as well as increase the reliability of long-term water supplies.

In the planning and implementation of multiple uses of water, the intended water reuse applications govern the degree of wastewater treatment required and the reliability of wastewater treatment processing and operation. In principle, wastewater or any marginal quality waters can be used for any purpose as long as adequate treatment is provided to meet the water quality requirements for the intended use. The dominant applications for the use of reclaimed water include: agricultural irrigation, landscape irrigation, industrial recycling and reuse, and groundwater recharge. Among them, agricultural and landscape irrigation are widely practiced throughout the world with well-established health protection guidelines and agronomic practices.

Water Reuse Definitions

To facilitate communication among different groups associated with water reuse, it is important to understand the terminology used in the arena of water reclamation and reuse. *Wastewater reclamation* is the treatment or processing of wastewater to make it reusable, and *water reuse* is the use of treated wastewater for beneficial purposes such as agricultural irrigation and industrial cooling. *Reclaimed water* is a treated effluent suitable for an intended water reuse application. In addition, *direct* water reuse requires the existence of pipes or other conveyance facilities for delivering reclaimed water. *Indirect* reuse, through discharge of an effluent to receiving water for assimilation and withdrawals downstream, is recognized to be important but does not constitute *planned direct* water reuse. In contrast to direct water reuse, *water recycling* normally involves only one use or user and the effluent from the user is captured and redirected back into that use scheme. In this context, water recycling is predominantly practiced in industry [2].

Role of Multiple Uses of Water in the Hydrologic Cycle

The inclusion of planned water reclamation, recycling and reuse in water resource systems reflects the increasing scarcity of water sources to meet societal demands, technological advancements, increased public acceptance, and improved understanding of public health risks. As the link between wastewater, reclaimed water, and water reuse applications has become better understood, increasingly smaller recycle loops are possible. Traditionally, the hydrologic cycle has been used to represent the continuous transport of water in the environment. The water cycle consists of fresh-water and salt-water surface resources, subsurface groundwater, water associated with various land use functions, and atmospheric water vapor. Many sub-cycles to the hydrologic cycle exist including the engineered transport of water. Wastewater reclamation, recycling and reuse represent significant multiple uses of water components of the hydrologic cycle in urban, industrial, and agricultural areas.

A conceptual overview of the cycling of water from surface and groundwater resources to water treatment facilities, irrigation, municipal, and industrial applications, and to wastewater reclamation and reuse facilities is shown in Figure 1.

to differences in specific water use requirements and geopolitical constraints.

- ***Agricultural irrigation*** represents the largest current use of reclaimed water throughout the world. This reuse category offers significant future opportunities for water reuse in both industrialized countries and developing countries.
- ***Landscape irrigation*** is the second largest user of reclaimed water in industrialized countries and it includes the irrigation of parks; playgrounds; golf courses; freeway medians; landscaped areas around commercial, office, and

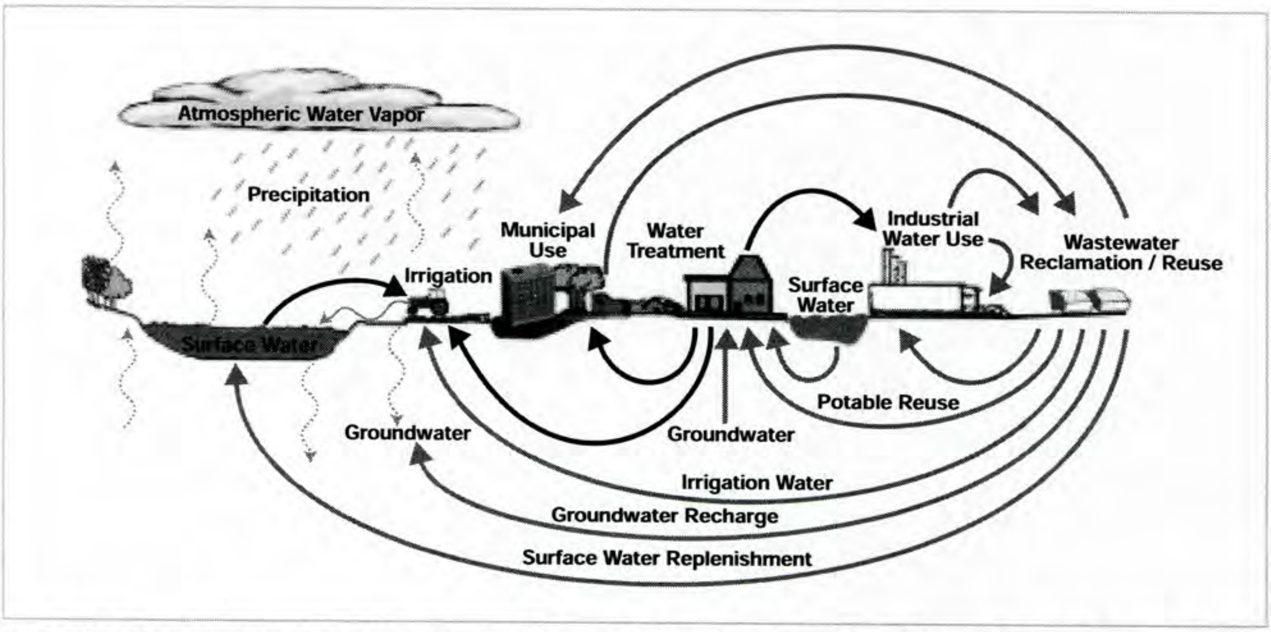

Figure 1. The role of engineered treatment, reclamation, and reuse facilities in the multiple uses of water through the hydrologic cycle. (adapted from Ref. [3])

industrial developments; and landscaped areas around residences. Many landscape irrigation projects involve dual distribution systems, which consist of one distribution network for potable water and a separate pipeline to transport reclaimed water.

The major pathways of multiple uses of water include irrigation, industrial use, surface water replenishment, and groundwater recharge. Surface water replenishment and groundwater recharge also occur through natural drainage and through infiltration of irrigation and storm water runoff. The quantity of water transferred via each pathway depends on the watershed characteristics, climatic and geohydrologic factors, the degree of water utilization for various purposes, and the degree of direct or indirect water reuse.

Categories of Water Reuse

In the planning and implementation of water reclamation and reuse, the reclaimed water application will usually govern the type of wastewater treatment needed to protect public health and the environment, and the degree of reliability required for each sequence of treatment processes and operations. From a global perspective, multiple uses of water have been developed to replace or augment water resources for specific applications, depending on local water use patterns. In general, water reuse applications fall under one of seven categories: (1) agricultural irrigation, (2) landscape irrigation, (3) groundwater recharge, (4) industrial reuse, (5) environmental and recreational uses, (6) non-potable urban uses, and (7) indirect or direct potable reuse. The relative amount of water used in each category varies locally and regionally due

- ***Industrial activities*** represent the third major use of reclaimed water, primarily for cooling and process needs. Cooling water creates the single largest industrial demand for water and as such is the predominant industrial water reuse either for cooling towers or cooling ponds. Industrial uses vary greatly and water quality requirements tend to be industry-specific. To provide adequate water quality, supplemental treatment may be required beyond conventional secondary wastewater treatment.
- ***Groundwater recharge*** is the fourth largest application for water reuse, either via spreading basins or direct injection to groundwater aquifers. Groundwater recharge includes groundwater replenishment by assimilation and storage of reclaimed water in groundwater aquifers, or establishing hydraulic barriers against salt-water intrusion in coastal areas. There have been a considerable interest in groundwater recharge projects in the United States of America and the European Union countries in recent years.
- ***Recreational and environmental uses*** constitute the fifth largest use of reclaimed water in industrialized countries and involve non-potable uses related to land-based water features

such as the development of recreational lakes, marsh enhancement, and stream flow augmentation. Reclaimed water impoundments can be incorporated into urban landscape developments. Man-made lakes, golf course storage ponds and water traps can be supplied with reclaimed water. Such water has been applied to wetlands for a variety of reasons including: habitat creation, restoration and/or enhancement, provision for additional treatment prior to discharge to receiving water, and provision for a wet weather disposal alternative for reclaimed water.

- ***Non-potable urban uses*** include fire protection, air conditioning, toilet flushing, construction water, and flushing of sanitary sewers. Typically, for economic reasons, these uses are incidental and depend on the proximity of the wastewater reclamation plant to the point of use. In addition, the economic advantages of urban uses can be enhanced by coupling with other ongoing reuse applications such as landscape irrigation.
- ***Potable reuse*** is another water reuse opportunity, which could occur either by blending in water supply storage reservoirs or, in the extreme, by direct input of highly treated wastewater into the water distribution system. Although the likelihood of implementing this option in the USA and the EU is remote, an example includes the City of Windhoek, Namibia because of the severe water shortage.

Spectrum of Reclaimed Water Quality

As water is used for various applications, the quality changes will occur as a consequence of introducing various constituents. A conceptual comparison of the extent to which water quality changes through municipal applications is shown in Figure 2. Water treatment technologies are applied to produce high-quality drinking water that meets applicable USA federal and state or EU and international standards for domestic (drinking) water supply. Conversely, municipal and industrial water use tends to degrade water quality by introducing chemical or biological contaminants. The quality changes necessary to upgrade the wastewater then become the basis

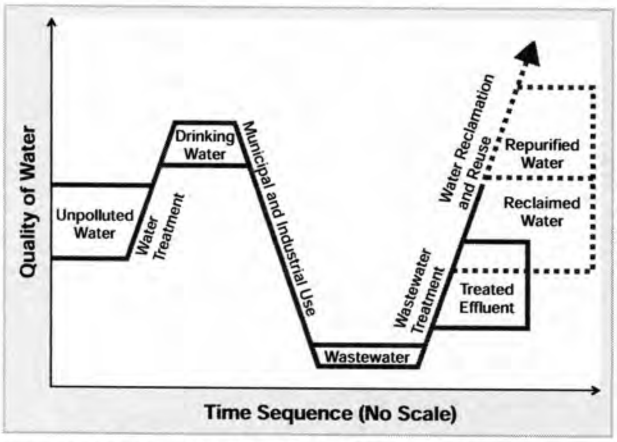

Figure 2. Water quality changes during municipal uses of water in a time sequence. (adapted from Ref. [4])

for wastewater treatment. In practice, treatment is carried out to the point required by regulatory agencies for protection of the aquatic environment and other beneficial uses. The dashed line in Figure 2 represents an increase in treated water quality as necessitated by multiple uses of water via reclamation and reuse. Ultimately, as the quality of treated water approaches that of unpolluted natural water, the practical benefits of water reclamation and reuse are evident.

As more advanced technologies are applied for water reclamation, such as carbon adsorption, advanced oxidation, reverse osmosis, and ultraviolet disinfection, the quality of reclaimed water can exceed conventional drinking water quality by most water quality parameters, and it is termed *repurified* water (City of San Diego, California, USA) and *NEWater* (Singapore). Today, technically proven water reclamation or water purification processes exist to provide water of almost any quality desired.

Water Quality Criteria and Regulatory Considerations

To protect public health without unnecessarily discouraging multiple uses of water, regulatory approaches stipulate water quality standards in conjunction with requirements for treatment, sampling, and monitoring. With reclaimed water, as in many activities, a key concern is the potential risk of human exposure to pathogenic organisms. However, controlling the extent of human exposure to the reclaimed water and ensuring that the wastewater treatment system is effective and reliable can minimize health impacts. The degree of treatment required and the associated monitoring requirements tend to be related to the specific water reuse application. In general, irrigation systems are categorized according to the potential degree of human exposure. To produce reclaimed water that is virtually pathogen-free, a higher degree of treatment is required for irrigation of crops that are consumed uncooked, or when reclaimed water is used for irrigation of locations that are likely to have frequent human contact.

The World Health Organization guidelines [5] emphasize that a series of wastewater stabilization ponds is necessary to meet microbial water quality requirements. Microbiological monitoring requirements also vary considerably among different jurisdictions: the WHO guidelines require monitoring of intestinal nematodes; whereas the State of California's *Water Recycling Criteria* [6] require more stringent set of conditions and prescribe wastewater treatment system reliability and monitoring of the effluent turbidity and the total coliform density for assessment of microbiological quality. The main concerns for water reuse in the United States of America are the elimination of enteric viruses and emerging bacterial and protozoan pathogens. For most developing countries, the greatest concerns associated with the use of wastewater for irrigation are to prevent exposure to enteric *helminths* such as hookworm, *ascaris, trichuris*, and under certain circumstances, the beef tapeworm. These pathogens can damage the health of the general public consuming the crops irrigated with untreated or partially treated wastewater. In addition, sewage farm workers and their families may experience more serious health risks.

Future Directions for Water Reuse

In many parts of the world, agricultural irrigation using reclaimed water has been practiced for many centuries. Landscape irrigation such as irrigation of golf courses, parks and playgrounds has been successfully implemented in many urban areas for over 30 years. Salt management in irrigated croplands may require special attention in many arid and semi-arid regions. Beyond irrigation and non-potable urban reuse, indirect or direct potable reuse need careful evaluation and close public scrutiny. It is obvious from public health and acceptance standpoints that non-potable water reuse options must be exhaustively explored prior to any notion of indirect or direct potable reuse.

Groundwater recharge with reclaimed water and direct potable water reuse share many of the public health concerns encountered in drinking water withdrawn from polluted rivers and surface water reservoirs. Three classes of constituents are of special concern where reclaimed water is used in such applications:
(1) enteric viruses and other emerging pathogens;
(2) organic constituents including industrial and pharmaceutical chemicals, residual home cleaning and personal care products and other persistent pollutants;
(3) salts and heavy metals.

The ramifications of many of these constituents in trace quantities are not well understood with respect to long-term health effects. For example, there are concerns about exposure to chemicals that may function as endocrine disruptors; also the potential for development of antibiotic resistance is of concern. As a result, regulatory agencies are proceeding with extreme caution in permitting water reuse applications that affect potable water supplies. In each case in the USA where potable water reuse has been contemplated, alternative sources of water have been developed in the ensuing years and the need to adopt direct potable water reuse has been avoided.

As the proportional quantities of treated wastewater discharged into the receiving water increases, much of the research which addresses groundwater recharge and potable water reuse is becoming of equal relevance to *unplanned direct potable reuse* such as drinking water intakes located downstream from wastewater discharges or from increasingly polluted rivers and surface water reservoirs. Examples include New Orleans, Louisiana on the Mississippi River and the Rhine Valley communities along the Rhine River in Germany and the Netherlands.

Reclaimed water is a locally controllable water resource that exists right at the doorstep of the urban environment, where water is needed the most and priced the highest. Closing the loop of the water cycle and implementing multiple uses of water not only are technically feasible in industries and municipalities but also makes economic sense. While potable reuse is still a distant possibility and may never be implemented except under extreme conditions, groundwater recharge with advanced wastewater treatment technologies is a viable option backed by the decades of experiences in several countries. Multiple uses of water via reclamation and reuse have become an essential element of future water resources development in *integrated water resources management*; thus, our opportunities and challenges will continue well into the 21st century.

Acknowledgments: Because this paper was written in a general and introductory manner, most materials were taken from author's previous publications with several co-authors. More detailed reference can be found in the recent publication [4].

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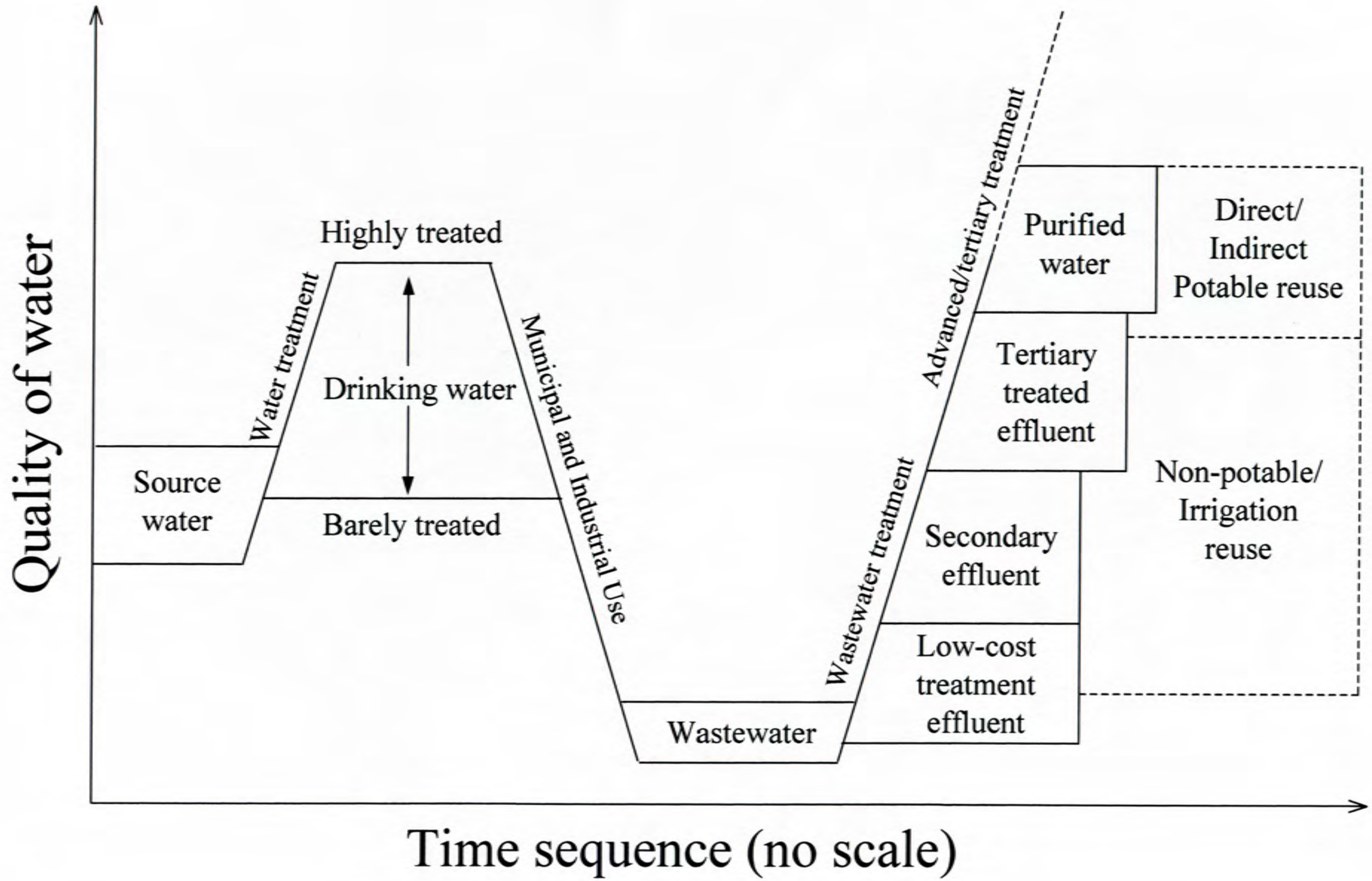
Quality of water
Source water
Water treatment
Highly treated
Drinking water
Barely treated
Municipal and Industrial Use
Wastewater
Wastewater treatment
Low-cost treatment effluent
Secondary effluent
Tertiary treated effluent
Advanced/tertiary treatment
Purified water
Direct/ Indirect Potable reuse
Non-potable/ Irrigation reuse
Time sequence (no scale)