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Preface

The UNESCO Chair in Water and Environment Management for Sustainable Cities was established in 2012 at Sharif University of Technology (SUT). One of the aims of the UNESCO Chair is to expand outreach of higher education and research through the exchange of knowledge and sharing, in a spirit of international solidarity. In spirit of this mission, the UNESCO chair office at the SUT is devoting efforts to tackle issues concerning the water shortage problem in Iran and the regional areas.

Water scarcity in dry and semi-arid regions such as Iran is a serious issue. In most water short areas, scarcity problems are affected by both natural and human factors. Perhaps, the most important human factor is improper management of water that is exacerbated further by limited availability of surface and groundwater resources. To offset the effects of a lower per capita level of the renewable water, a comprehensive sustainable integrated water resources management plan must be developed. Any sustainable integrated water management plan should include a water reuse program with a wide range of non-potable and potable reuse applications. Establishing a comprehensive water management plan along with water reuse program is a critical step that should be taken to help alleviate current and future water scarcity problems in Iran and other water stressed regions.

Recognizing the importance of this subject to Iran and the region, the UNESCO chairholder, Dr. Ahmad Abrishamchi, in Water and Environment Management for Sustainable Cities at Sharif University of Technology requested that knowledgeable experts submit papers on the potential of potable water reuse in Iran and the region. This technical paper was prepared in response to the above request and was published previously in Farsi in the Iranian Journal of Water and Wastewater. The publication of this technical paper in English on the UNESCO web site, makes it possible for it to be accessed by a larger audience. In addition, the information and concepts presented in this technical paper would be a valuable contribution to the achievement of Goal 6 (Clean Water and Sanitation) of the UN Sustainable Development Goals. The UNESCO chair in Water and Environment Management for Sustainable Cities at Sharif University of Technology hopes that the material presented in this technical paper will be useful to general readers and regional governmental agencies when considering water reuse program.

Executive Summary

As Iran moves forward with the development of a sustainable integrated water management plan, water reuse, including the potable reuse, can play an important role in the overall success and implementation of the plan. As part of this effort, the authors in cooperation with UNESCO Chair in Water and Environment Management for Sustainable Cities at Sharif University of Technology (SUT) prepared this technical paper, to be published online by the UNESCO chair at the SUT. This technical paper, presented in six parts, deals specifically with the potential application of reclaimed water for potable reuse in Iran and other regional countries with similar climate and environmental conditions.

Topics addressed in Part 1 include a description of water shortage problem in Iran, and consideration for why potable water reuse in Iran. Background information on potable water reuse along with a comparative assessment of potable water reuse with alternative sources of water supplies is presented in Part 2. Public health considerations in potable reuse, representative advanced water treatment trains and the use of environmental buffers used in potable reuse are considered in Part 3. The importance of source control and the need to upgrade existing and new secondary wastewater treatment facilities for water reuse applications including potable reuse is discussed in Part 4. The path forward for potable water reuse in Iran, along with the implementation challenges, is considered in Part 5. Closing thoughts are presented in Part 6.

While the material on potable reuse is timely and of interest, the authors believe that the most important issue for Iran and the region is the adoption of a national sustainable water resources management program, which includes both non-potable and potable reuse as part of their overall water portfolio, to meet future water needs. In this connection, the use of distributed wastewater treatment in Iran's large cities will lead to a more sustainable utilization of the available water supply. Initially, it is anticipated the most reuse applications would be non-potable, but that in the near future potable reuse will become a reality. It is hoped that material presented in this technical paper will be useful to local and regional governmental agencies when considering water reuse, especially potable reuse, in the development of their water management plans.

Part 1: Introduction

The purpose of Part 1 is to provide some background material on the water shortage problems in Iran and to consider why potable reuse in Iran is feasible. The information presented in part 1 is important in assessing the material presented in the subsequent parts as well as the role of potable reuse in Iran. Potable water reuse is introduced in Part 2. Technical and regulatory issues for potable reuse are presented in Part 3. Source control and enhanced wastewater treatment for non-potable and potable reuse applications are discussed in Part 4. The path forward and implementation challenges, including public outreach, are considered in Part 5. Closing thoughts are presented in Part 6.

1.1. Background information

Iran's water shortage problem is imminent, and something must be done before the issue of water scarcity becomes unmanageable. The water shortage problem in Iran is associated with multiple factors including the limited availability of surface and groundwater. The available renewable water per capita in Iran was reported to be less than 1700 m^3 in 2006 and is projected to drop to 1100 m^3 by 2020. According to Damkjaer and Taylor (2017) when the water availability thresholds index for a country or region reach levels of 1700 m^3 and 1000 m^3 per capita, the country or region is categorized as *stressed* or *scarce*, respectively. Based on the above thresholds index values, Iran is currently at the stressed level and will be in the scarce level in the near future. If the scare level is to be avoided, Iran must adopt a sustainable integrated water management plan including of an effective water reuse program (Kayhanian and Tchobanoglous, 2016).

Implementing sustainable water management plan along with a water reuse program, will allow Iran to potentially expand its available renewable water supply by:

- Substituting treated wastewater for applications that do not involve human consumption (e.g., non-potable water reuse),
- Augmenting existing water sources and providing additional sources of potable water to assist in meeting both present and future water needs,
- Protecting the aquatic systems by decreasing the diversion of freshwater as well as reducing the quantity of nutrients and other toxic pollutants entering waterways,
- Reducing the need for expensive water control structures, and
- Complying with regulations by managing wastewater discharges into the environmental.

At present, the water reuse in Iran is in early development stage and much of the limited reclaimed water is reused for non-potable application; especially in agricultural sectors (Eslamian and Tarkesh, 2007; Razaghi et al., 2011; Tajrishy et al., 2014). The lack of a well-developed water reuse program in Iran is related partially to the limited availability of centralized wastewater collection and wastewater treatment infrastructure. In recent years, Iran has paid special attention to the sanitary conditions of urban cities as well as constructing more wastewater collection networks and centralized wastewater treatment plants. One example of this progress is the construction of a large centralized wastewater treatment plant in southern Tehran with a full operating capacity of about one million cubic meters per day (1 MCM/day). Numerous other wastewater treatment plants are also planned or under construction in Tehran and other urban cities throughout Iran. In fact, Iran is planning to collect and treat about 75 percent of its wastewater throughout the country within the next 15 years. Ideally, treated effluent from these wastewater treatment plants can be used for multiple reuse applications (including potable reuse) without overdrawing the limited existing surface water and groundwater supplies.

Developing a water reuse program where reclaimed water is used for a wide range of non-potable and potable reuse applications is an essential component of an integrated and sustainable water resources management plan. As part of this effort, the authors in cooperation with the UNESCO chair in water and environment management on sustainable cities at Sharif University of Technology (SUT) prepared this technical paper to be published online and maintained by UNESCO chair office at the SUT.

1.2. Why potable reuse in Iran?

The question of why potable reuse in Iran can be answered by considering how cities in the future will become sustainable. One of the principal components of sustainable cities throughout the world and in Iran will be a sustainable reliable water supply. At present, with limited surface water availability in large cities, the communities in Iran are relying on groundwater as a major sources of water supply. In the past 50 years, Iran has used about 70 percent of the groundwater supply, which took a million years to store underground. If nothing is done the disparity between the recharge and extraction of groundwater resources will become even greater. This disparity has resulted in land subsidence, salt intrusion, and lowering of the water table throughout Iran. The depleted underground water could be augmented with water reuse for both non-potable and potable application. In the past, the reclaimed water was only used for non-potable applications in urban areas. But, with advanced treatment technology and the utilization of decentralized wastewater treatment facility; it is now possible to use the reclaimed water for potable reuse. As discussed previously, potable reuse is a more attractive option than desalination for inland urban areas. Potable reuse is also an attractive alternative when compared to imported water as it requires less energy and has a lower carbon footprint. In addition, in the long run, potable water reuse is more sustainable for urban areas. Finally, potable reuse will reduce the burden on surface and groundwater resources.

Part 2: Potable Reuse Compared to Other Potable Water Supplies

Potable reuse (PR) involves the use of a community's wastewater, after extensive treatment, as a potable water source. In this context, wastewater is no longer viewed as a waste requiring disposal, but as a *renewable recoverable source of drinking water, resources, and energy* (Tchobanoglous, 2012. The types of potable reuse, elements of potable water reuse, and representative examples of potable reuse projects are considered in this part of the technical paper.

2.1. Potable reuse types

The principal types of potable reuse practiced currently in the world include *unplanned* and *planned* potable reuse. Unplanned potable reuse, often identified as *de facto* potable reuse, occurs when downstream surface waters subject to upstream wastewater discharges are used as a source of drinking water. *De facto* potable reuse is a common occurrence in many drinking water supplies derived from surface water sources, principally rivers (NRC, 2012), and has been understood for at least 100 years, including how to address its issues and challenges (Hazen, 1914). Unfortunately, *de facto* potable reuse is not recognized officially as water reuse (U.S. EPA, 2012) and when water reuse is discussed in the literature it is usually only related to *planned* potable reuse.

There are two types of *planned* PR: (1) *indirect potable reuse (IPR),* and (2) *direct potable reuse (DPR).* The two different types of PR are illustrated in Figure 2.1 and described in Table 2.1. The principal difference between the two types of PR is as follows. In IPR, advanced treated water is introduced into an environmental buffer (e.g., groundwater aquifer or surface water body) to assure the safety of the advanced treated water by providing sufficient retention time and to lose its identity by blending with other local water before being withdrawn for potable reuse. Environmental buffers for IPR are consider further in Part 3.

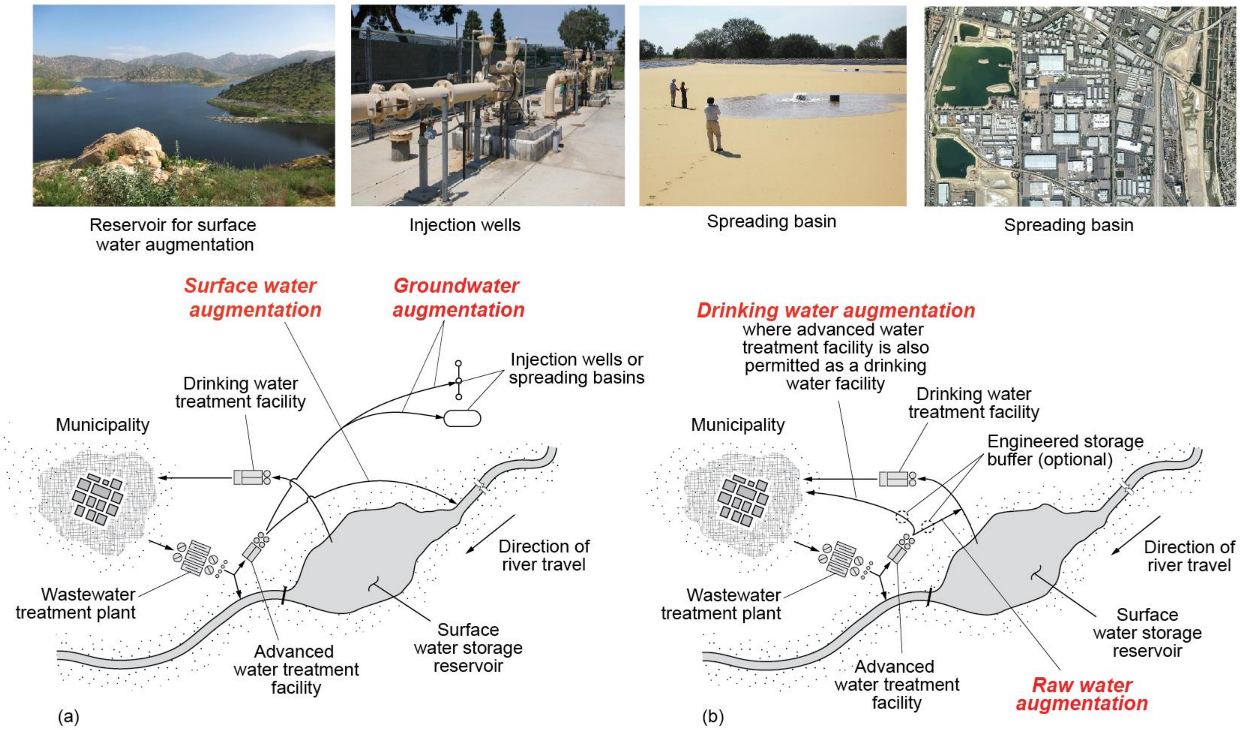

Figure 2.1 Pictorial view of two different types of potable reuse (a) IPR through groundwater and surface water augmentation and (b) DPR through raw and drinking water augmentation (Adapted from Asano et al., 2007)

In DPR, advanced treated water is used to augment a raw water supply by blending with other water before the combined stream is treated in a drinking water treatment plant. If the advanced water treatment facility is also permitted as a drinking water plant, finished water could potentially be discharged directly into the potable water distribution system [see Figure 2.1(b)]. In both applications, the optional engineered storage buffer (ESB) may be used. The purpose of the ESB is to: (1) provide a water storage containment facility of sufficient volumetric capacity to retain advanced treated water (ATW) for a specified period of time until process or system corrections can be made, if there is a plant failure; (2) prevent blending of ATW that does not meet water quality standards with other sources of raw water; and (3) to prevent the addition of finished ATW that does not meet water quality standards to the drinking water distribution system (Tchobanoglous et al., 2011). Because of the many unknowns and public health concerns, DPR systems that discharge finished ATW directly to the potable water distribution system are less common. Such DPR systems are not recommended for Iran and, hence are not considered in this technical paper. In the future, as more information becomes available and additional operating experience is gained with finished water augmentation DPR systems, the direct discharge to a community potable water distribution may become feasible.

Table 2.1 Terminology used to describe the different type of potable reuse (PR)

PR type	Definition
Water reuse terminology commonly used in the literature:	
De facto PR	The downstream use of surface water as source of drinking water that is subject to upstream wastewater discharges (e.g., also referred to as unplanned PR or indirect PR). Although common practice in many parts of the world including the United States, *de facto* PR is not officially recognized by the U.S. EPA.
Indirect PR (IPR)	The introduction of advanced treated water into an environmental buffer such as a groundwater aquifer or a water body before being withdraw for potable purposes (see also *de facto* PR). IPR can also be accomplished with tertiary effluent when applied by spreading to take advantage of soil aquifer treatment.
Direct PR (DPR)	There are two forms of DPR. In the first form, advanced treated water (ATW) is introduced into the raw water supply upstream of drinking water treatment facility. In the second form, finished drinking water from an AWTF permitted as a drinking water treatment facility is introduced directly into a potable water supply distribution system. In both forms of DPR, use of an engineered storage buffer is optional.
Water reuse terminology adapted in California on October 2017 (AB 574):	
Direct PR (DPR)	The planned introduction of recycled water directly into a public water system or into a raw water supply immediately upstream of a water treatment plant.
Raw water augmentation (RWR)	The planned placement of recycled water into a system of pipeline or aqueducts that deliver raw water to a drinking water treatment plant that provides water to a public water system.
Treated drinking water augmentation (TDWA)	The planned placement of recycled water into the water distribution system of a public water system, as defined in Section 116275 of the Health and Safety Code.
IPR for groundwater recharge (IPRGR)	The planned use of recycled water for replenishment of a groundwater basin or an aquifer that has been designed as a source of water supply for a public water system.
Reservoir water augmentation (ReWA)	The planned placement of recycled water into a raw surface water reservoir used as a source of domestic drinking water supply for a public water system, as defined in Section 116275 of the Health and Safety Code, or into a constructed system conveying water to such a reservoir.

Also, as reported in Table 2.1, California adopted new terminology (AB 574) for potable water reuse in October 2017. Although the various abbreviations for the potable reuse terminology adopted by California are different, the meaning is essentially the same as that of the commonly used terminology. To eliminate the confusion, in the future, every effort should be made to standardize the terminology used in describing PR.

2.2. Principal elements of potable reuse system

The key elements for the successful implementation of a sustainable PR system include: (1) regulatory considerations, (2) technical issues related to the production of safe drinking water, and (3) public outreach. These three key elements are interrelated as illustrated in Figure 2.2. The success of a PR program in relationship to each of these key elements is discussed briefly in this section. More detail information about the potable reuse implementation issues may be found in Tchobanoglous et al. 2015.

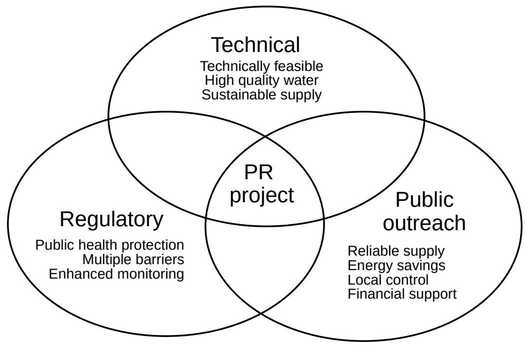

Figure 2.2 Interrelationship of the key elements of a potable reuse system (Adapted from Tchobanoglous et al. 2015)

2.2.1. Regulatory element

The first element in the implementation of a PR program is the regulatory compliance issues to protect public safety. At present, no standardized regulations have been adopted for PR in the United States. However, regulations already exist based in the clean water act (CWA) and the safe drinking water act (SDWA) that allow for planned potable reuse implementation. In the United States, utilities and states must meet all applicable SDWA and CWA provisions, at a minimum, when implementing planned potable reuse projects. With the lack of standardized regulations from U.S. EPA, some states, have established rules, regulations, or guidance for IPR and DPR project implementation. According to U.S. EPA, currently 14 states (Arizona, California, Florida, Hawaii, Idaho, Massachusetts, Nevada, North Carolina, Oklahoma, Oregon, Pennsylvania, Texas, Virginia, Washington) have regulatory guidance on IPR projects and 3 states have regulatory guidance on DPR projects (U.S. EPA, 2017). It should be noted that interest in implementing DPR projects is increasing and it is expected that more states will establish regulatory guidance in the future. From public safety point of view, DPR regulations are similar to IPR regulations; however, additional requirements for DPR may be included, such as added monitoring and operational requirements to account for the lack of a natural environmental buffer and the need for appropriate response times.

Based on the knowledge of the authors, at present no standard water quality regulations for PR have been adopted in Iran. Even with lack of regulation for PR in Iran, it is reasonable to assume that the treated water must comply with applicable Iranian drinking water laws, regulations, rules, guidelines, or criteria to produce safe drinking water. Initially, existing IPR and DPR regulations from individual states in the United States could be adapted for a PR program in Iran, until the Iranian water authority can develop regulations of their own.

2.2.2. Technical element

The second key element of a successful and sustainable PR program is related to technical issues. The key technical components for a PR system include (Tchobanoglous et al., 2015):

- Source of water supply (e.g., surface water and/or groundwater).
- Source control program.
- Wastewater treatment.
- Advanced water treatment.
- Engineered storage buffer (ESB), if needed.
- Environmental buffers
- Drinking water treatment.
- Associated piping and pumping infrastructure—including the water distribution system, wastewater collection system, and ATW transport system—to the location where it will be introduced into the DWTF or distribution network.

Detail information on each of the above items is beyond the scope of this technical paper. However, some of the issues related to the above elements are summarized in Table 2.2. Additional detail information related to the importance of source control, secondary wastewater treatment upgrades, advanced water treatment, and environmental buffers pertinent to PR projects is presented in Parts 3 and 4.

Table 2.2 Important issues related to the technical elements of a potable reuse program

Technical element	Issues/comments
Water supply sources	• Assess what level of blending, if any, is needed based on quality of ATW and different water sources. • Develop an operation plan for blending ATW with alternative water sources. • If needed, modify existing system to allow for blending and stabilizing the ATW. • Investigate various blend ratios and rationales for target blend rate range.
Source control program for community or service area	• Identify constituents in wastewater that may be difficult to remove or are precursors to disinfection byproduct formation (depending on treatment technologies used). • Information is needed on sources and concentrations of selected constituents. • Include commercial and industrial entities in source control program. • Develop a program to inform consumers of best practices for home waste disposal.
Wastewater treatment	• Identify alternative technologies that can enhance performance of existing and new treatment plants. • Determine optimum location, size, type of flow equalization (inline or offline), and quantify its benefits on performance and reliability of biological and other treatment processes. • Quantify benefits of complete nitrification or nitrification and denitrification on performance of membrane treatment processes used for PR. • Evaluate optimization of conventional processes (i.e., primary, secondary, and tertiary) to improve overall treatment and reliability of entire system. • Implement a monitoring scheme to ensure treatment performance for each unit process and end-of-process validation of water quality.
Advanced water treatment	• Evaluate alternative treatment schemes with and without demineralization that can be used to treat water. • Define technical and operational requirements for a reliable system. • Develop a monitoring scheme to ensure treatment performance for each unit process and end-of-process validation of water quality. • Select constituents and parameters for monitoring in advanced water treatment processes, including analytical methods, detection limits, and frequency. • Provide standby power systems in the event of power loss or another type of emergency. • Identify process redundancy so treatment trains can be taken offline for maintenance. • Provide facilities for discharge of off-spec water in the event that water does not meet established quality requirements for influent to DWTF. Example discharge locations include the WWTP, a point in the AWTF, or into the environment.
Engineered storage buffer	• Evaluate need for and type of ESB. • Define impact of existing monitoring response times, as well as analytical, detection, and monitoring capabilities, to assess configuration, size, and features of an ESB.
Environmental buffer	• Identify potential environmental buffers (e.g., groundwater basins, surface water reservoirs, natural lakes) • Determine capacity of environmental buffers to receive advanced treated water. • Estimate the retention time for blended water at different points of injection
Drinking water treatment	• Mix of source water and ATW should not impact water treatment process or adversely impact finished water quality. • Additional treatment, monitoring, and testing may be required.
Engineering infrastructure (piping and pumping)	• Investigate potential impacts of ATW on drinking water distribution system (e.g., corrosion issues).

Source: Adapted from Tchobanoglous et al., 2015.
Notes: ATW = advanced treated water; AWTF = advanced water treatment facility; DWTF = drinking water treatment facility; DPR = direct potable reuse; ESB = engineered storage buffer; WWTP = wastewater treatment plant.

2.2.3. Public outreach element

The third and final element related to the implementation of a PR program is public outreach. A public outreach program is needed to build public confidence and support of the use of reclaimed water produced from advanced water treatment facilities (AWTFs) as a source of drinking water supply. The public outreach program ideally should launch during the early stages of planning and be maintained throughout the lifetime of the project. Beside the issue of accepting the use of reclaimed water as a source of drinking water, public outreach may also emphasize the importance of reliable local water availability and energy savings that is commonly associated with PR. In addition, the cost issues should be shared with public when considering a PR project. Further information on challenge to overcoming the barrier associated with public perception and public acceptance in Iran is presented in Part 5.

2.3. Representative examples of potable reuse projects

Representative examples of successful PR project are presented in Table 2.3. At present, according to the U.S. EPA there are 16 PR projects in operation in the United States with total capacity of about 0.74 million cubic meters per day (MCM/d). Similarly, 8 PR projects are actively operating in international countries with total capacity of about 0.9 MMC/d. Multiple other PR projects are under study, construction and planning stages; both in the United States and abroad. The summary of all ongoing, under construction or planed PR projects in the U.S and abroad are summarized in the new U.S. EPA potable reuse compendium report (U.S. EPA, 2017).

Table 2.3 Representative examples of successfully operated potable reuse (PR) project [a]

PR project name and location	PR type	Installation year	Plant size (MMC/d)	Overview of treatment trains employed
Orange County Water District Groundwater Replenishment System (OCWD GWRS), California	IPR: Groundwater recharge via surface spreading and direct injection (IPRGR)	2008 expanded in 2016	0.38	WWTP → UF → RO → UV/AOP → blending with groundwater → conventional water treatment
Upper Occoquan Sewage Authority, Virginia	IPR: Surface water augmentation (ReWA)	1978	0.20	WWTP → LC → media filtration → GAC → IX → Cl → blending with surface water body → conventional water treatment
Big Spring Colorado River Municipal Water District, Texas	DPR: blending prior to water treatment (TDWA)	2013	0.007	WWTP → MF → RO → UV/AOP → blended with treated surface water body → conventional water treatment
City of Windhoek, Namibia	DPR: blending prior to water treatment (TDWA)	1969; expanded in 2002	0.02	WWTP → PAC → O_3 → Clarification → DAF → sand filtration → O_3/AOP → BAC/GAC → UF → Cl → blended with treated surface water → conventional water treatment
NEWater, multiple locations in Singapore	IPR: Surface water augmentation (ReWA)	Two plants in 2003; new plant in 2010	0.60[b]	WWTP → UF → RO → UV → blending with surface water body → conventional water treatment

[a]Adapted from U.S. EPA, 2017. [b]Combined size for three plants

Potable reuse and treatment processes abbreviations: IPR= indirect potable reuse; IPRGR = IPR for groundwater recharge; DPR = direct potable reuse; RWR = raw water augmentation; TDWA = treated drinking water augmentation; ReWA = reservoir water augmentation; ADF = average daily flow; AOP = advanced oxidation processes; ASR = aquifer storage and recovery; BAC = biological activated carbon; Cl = chlorination; DAF = dissolved air flotation; GAC = granular activated carbon; IX = ion exchange; LC = lime clarification; MBR = membrane bioreactor; MF = microfiltration; O_3 = Ozone disinfection; PAC = powdered activated carbon; RO = reverse osmosis; UF = ultrafiltration; UV = ultraviolet radiation

2.4. Potable water reuse compared with the alternative water supplies

When determining whether to proceed with advanced treatment in a PR project, it is useful to perform analysis and compare it with the alternative water supplies. Important topics to be considered for comparative analysis include: (1) the issues associated with developing and implementing alternative water sources relative to those for PR, (2) comparative energy and the related carbon footprint, and (3) comparative cost consideration.

2.4.1. Comparison with other sources of water

With no additional water availability, two of the most immediate water supply alternatives for Iran may include importing surface water from neighboring countries and desalination of salt waters from Caspian Sea in northern and Persian Gulf in southern Iran. The challenging issues with respect to imported surface waters and desalination are compared and summarized in Table 2.4.

Table 2.4 Comparative issues with alternative sources of water supply to potable reuse

Alternative water supply source	Comparative issues
Imported Water	▪ With low availability of water, importing water within the country is not possible. Importing water from neighboring countries will be difficult, if not impossible, to develop; particularly considering the long-terms issues related to safety, security and reliability. ▪ Withdrawing water from inland areas, transporting it to population centers, treating and using it once, and discharging it to coastal waters is, in the long term, less sustainable than other options. ▪ Imported water sources: (1) are subject to natural and institutional disruptions and limitations, resulting in potentially large inter annual variability; (2) can be of variable quality (e.g., high salt load); (3) often require significant amounts of energy for transport; (4) can impose significant adverse environmental consequences when local water is extracted; (5) reduce potential environmental impacts of wastewater discharges to surface waters; and (6) are relatively expensive, the cost of which will continue to escalate in the future. ▪ Imported water is also subject to natural and societal forces that are difficult to control, including: (1) increased demands from population growth; (2) drought; (3) changes in snowpack, rainfall, or other natural sources of replenishment; (4) seismic events; and (5) future environmental regulations, water rights determinations, and associated political and legal challenges. ▪ In many locations, imported water increases local salt loading. ▪ Extensive treatment may be required for low-quality imported water sources.
Desalination	▪ Desalination of water from Persian Gulf and Caspian Sea is a technically feasible option that can provide a high-quality, potable supply after blending or chemical addition, but with a number of drawbacks, including: (1) potential environmental impacts associated with ocean feedwater intakes, brine disposal and discharges, and construction of facilities at sensitive shoreline or near-shore locations; (2) relatively high energy demands for treatment and especially for pumping to populated areas; (3) large carbon footprint; (4) feedwater quality that is vulnerable to red tides and other ocean water quality challenges; (5) coastal facilities that may be vulnerable to sea level rise and storm surges; and (6) security threats based catastrophic failure. ▪ Desalination of water from Caspian Sea or inland brackish water is less costly than the Persian Gulf water desalination because of much lower salt content; but has significant brine management challenges. ▪ Ocean desalination is more expensive than potable reuse, often by a factor of 2:1 per 3.78 L (1 gallon). ▪ When desalinated source water is recycled, it increases the amount of water available for local beneficial use.

Source: Adapted from Kayhanian and Tchobanoglous, 2016.

2.4.2. Comparative energy and the related carbon footprint requirements

The energy required and carbon footprint for advanced water treatment facility (AWTF) used in PR projects compared with imported water and desalination in Table 2.5. The data presented in Table 2.5 are generated in the United States and hence should only be viewed qualitatively rather than quantitatively. As shown, the potable reuse option is less energy intensive and has a lower carbon footprint as compared to the other two alternatives.

Table 2.5 Comparative energy requirements and carbon footprint for different alternative sources of surface water

Technology/water source	Energy required: Range (kWh/m^3)	Energy required: Typical (kWh/m^3)	Carbon footprint ($kg\ CO_2/m^3$)
AWTF	0.86–1.06	0.25	0.48
Backwash water desalination	0.82–1.64	0.41	0.77
Ocean desalination	2.51–3.89	0.84	1.58
Interbasin transfer of water, California, U.S.A.	2.09–2.62	0.64	1.21
Interbasin transfer of water, Colorado River, U.S.A.	1.62–1.95	0.43	0.81

Source: Adapted from Tchobanoglous et al., 2015.

2.4.3. Comparative costs

Comparative costs for treatment, residuals management, concentrate management, and conveyance facilities for an AWTF with other alternative sources are presented in Table 2.6. Again, the data shown in Table 6 are from the United States and should be viewed qualitatively rather than quantitatively. As shown, the cost range of producing clean potable reuse water from AWTF with/without RO is generally lower than the cost of the other alternatives. During the drought years, cost considerations are even more important.

Table 2.6 Comparative unit costs of advanced treated water with other water supply options

Water Supply Option	Cost ($\$/m^3$): Treatment	Residuals management	Concentrate management	Conveyance and blending facilities
AWTF with RO	0.55–0.72	0.008–0.04	0.06–0.63	0.08–0.81
AWTF without RO	032 [a] –0.57	0.008–0.04	Not applicable	0.08–0.81
Brackish groundwater desalination (inland)	0.33–0.67	0.005–0.02	0.06–0.63	0.08–0.81
Seawater desalination	1.58–2.83	0.02–0.08	0.06–0.16	0.32–2.43
Retail cost of treated imported surface water	0.32–1.05		Not applicable	0.08-0.49

Source: Adapted from Tchobanoglous et al., 2015.

Part 3: Regulatory and Technical Issues for Potable Reuse

The three principal components of potable reuse program, as noted in Part 2, are: technical, regulatory, and public outreach. Regulatory and technical and issues are considered in greater depth in this part of the technical paper. From the technical point of view, the appropriate design and operation of an advanced water treatment facilities (AWTFs) is an essential element of a successful implementation of a potable reuse project. The principal purpose of an AWTF in potable reuse projects is to produce water that meets all applicable drinking water quality standards and any other specific restriction applied by the local regulations. Topics considered in this section with respect to regulatory and technical issues include: (1) public health considerations in potable water reuse, (2) representative advanced treatment trains used in potable water reuse, and (3) the use of environmental buffers for potable water reuse. The importance of source control and the need to upgrade new and existing secondary wastewater treatment facilities for potable water reuse is considered in Part 4.

3.1. Public health considerations in potable water reuse

From public safety point of view, the goals of AWTFs are to eliminate acute risks (best exemplified by pathogens) and minimize potential chronic risks (best exemplified by chemical constituents) (U.S. EPA 2012). Hence, to protect public health, the selection and operation of treatment train processes is driven by several common regulatory requirements that typically include: (1) pathogen log reduction requirements, (2) low bulk organic constituent concentrations (e.g., TOC, COD), and (3) the use of multiple treatment barriers for the control of pathogens and chemical constituents. Additional detail information on the required criteria for pathogen log removal and the removal of trace organic chemical constituents are presented below.

3.1.1. Pathogens log removal requirements

In the United States, the potable water is regulated under appropriate drinking water regulations (i.e., the U.S. Clean Water Act (CWA) and the U.S. Safe Drinking Water Act (SDWA); administrated by the U.S. EPA. The drinking water quality standard and numerical values established by the U.S. regulations have been adapted with or without some modifications in many parts of the world including Iran. While potable reuse guidelines have been developed, and revised several times by the U.S. EPA, at present, no national regulatory water quality standards have been established for what total log reduction values should be achieved for pathogenic organism in potable reuse projects (U.S. EPA, 2017).

To date, the current pathogen log-reduction requirements in California are the most stringent: 12-log removal for enteric viruses, 10-log removal for *Cryptosporidium*, and 10-log removal for *Giardia*. These requirements were based on three assumptions: (1) a tolerable annual risk of infection of 10^{-4} per person per year, (2) tolerable microorganism concentrations based on dose response studies, and (3) worst-case microorganism concentrations in untreated wastewater (Olivieri et al. 2016). The basis for these log removal values is given in Table 3.1. It is assumed that these criteria would ensure water free of pathogenic microorganisms with a large margin of safety (probably greater than being achieved for many conventional water supplies) and, therefore, could be safely used for potable purposes.

Table 3.1 Basis for the log reduction values used by the State of California

Item	**Enteric Virus**	**Giardia**	**Cryptosporidium**
Untreated wastewater maximum concentration	10^5 virus/L	10^5 cysts/L	10^4 oocysts/L
Tolerable drinking water concentration (TDWC)	2.2×10^{-7} virus/L	6.8×10^{-6} cysts /L	1.7×10^{-6} oocysts /L
Ratio of TDWC to wastewater concentration	2.2×10^{-12}	6.8×10^{-11}	$1.7 \times 10^{--10}$
Required log reduction value	12	10	10

Source: Adapted from Olivieri et al., 2016.

At present, no single treatment process is capable of removing all of the pathogens to the log reduction values specified in Table 3.1. Hence, the only way to achieve the required pathogen log reduction values is to link together a series of independent, often redundant, unit treatment processes. The stringing together of multiple treatment processes is known as the "multiple barrier concept," of treatment. The multiple barrier concept is considered further under subheading 3.1.3. It should also be noted that alternative log removal values for pathogens have been established by the Texas Commission on Environmental Quality (TCEQ) and by an NWRI panel (NWRI, 2013) and others as summarized in Table 3.2.

Table 3.2 Examples of regulatory requirements from different sources for the log removal of pathogens and trace organic chemical constituents related to potable reuse projects

Regulatory source	Regulatory requirements	
	Log removal requirement for pathogens	**Trace organic chemical constituents limit based of TOC or COD concentration**
California	Pathogen log reduction values of 12-log for viruses, 10-log for *Cryptosporidium,* and 10-log for *Giardia* are required from the raw wastewater to the finished water. Multiple barriers are required indirectly by limiting the maximum pathogen log reduction credit granted to any treatment step to 6-log, which is significantly below the total log reduction requirements, and by requiring RO and AOP.	California's IPR regulations for subsurface application (i.e., groundwater injection) require the use of RO and limit TOC to less than 0.5 mg/L for the complete use of advanced treated water with no dilution.
Florida	Florida has not established pathogens log removal requirement, but specifically state that treatment "...shall include processes which serve as multiple barriers for control of pathogens".	For IPR the limit for TOC is specified to 3 mg/L and specifically state that treatment "...shall include processes which serve as multiple barriers for control of organic compounds".
Texas	The Texas Commission on Environmental Quality (TCEQ) uses WWTP effluent as the starting point for pathogen reduction requirements for DPR projects (in contrast, California uses raw wastewater as the starting point for IPR projects). Consequently, for DPR trains, TCEQ has established minimum log reduction values of 8.0-log for viruses, 5.5-log for *Cryptosporidium*, and 6.0-log for *Giardia*. These values may be increased by the TCEQ based on site-specific WWTP effluent concentrations.	Texas has not established TOC limits for potable reuse projects.
Virginia	Virginia has not established pathogen log removal values for potable reuse projects.	Virginia's Occoquan Policy, which is the regulatory policy defining requirements for the long- standing IPR project of the Upper Occoquan Service Authority, dictates a COD limit of 10 mg/L (approximately 4 mg/L of TOC).
Singapore	Singapore has not established pathogens log removal values for potable reuse projects.	The TOC limit has been established at 0.1 mg/L for NEWater, which is used for IPR through surface water augmentation.
NWRI	AWTFs should provide 12-log reduction for enteric viruses, 10-log reduction of Cryptosporidium, and 9-log reduction of total coliform bacteria.	NWRI research study was only focused on pathogens log removal and hence no trace organic chemical removal limit was established.

Numeric data reported in this table were adapted from Mosher et al., 2016, and NWRI, 2013.
NWRI = National Water Research Institute

3.1.2. Requirements for the removal of trace organic chemical constituents

In the United States, the treatment trains in AWTFs are selected in a manner that to comply with

all regulated chemicals and health advisories established by the U.S. EPA including five disinfection byproducts (DBPs) limits [i.e., trihalomethanes, haloacetic acids (or halogenated acetic acids), NDMA, bromate, and chlorate]. Many chemical constituents with established numeric regulatory standard values [e.g., the maximum contaminant level (MCL)] must be met through the advanced treatment process. In most cases, trace levels of non-regulated chemical constituents (typically measured in the μg/L or ng/L level) have been shown to be below health significance levels (Trussell et al., 2015). However, to increase public confidence and as a precaution against unknown constituents in treated wastewater it may be reasonable to further treat water to assure reliable removal of trace chemical constituents and toxic chemicals.
Two other categories of chemicals that need to be monitored when evaluating the efficiency of treatment train performance include: (1) unregulated chemicals of interest from the standpoint of public health, and (2) compounds useful for evaluating the removal of organic chemicals during various types of treatment.

The removal efficacy of trace organic chemicals (TrOCs) by advanced treatment trains in potable reuse projects is usually measured through surrogate parameters such as TOC and COD. Hence, the presence of TrOCs and other chemical constituents in water from AWTFs have been controlled through specific TOC or COD regulatory limits, maximum contaminant levels, and notification limits for specific organic chemicals (e.g., SOCs, VOCs), and the requirement for additional treatment processes (e.g., advanced oxidation in California). It is also important to note that the validity of the use of surrogate aggregate parameters such as TOC and COD for the control of TrOCs has been questioned, because these surrogates may not accurately reflect toxicity caused by the presence of TrOCs and, therefore, the safety of advanced treated water.

As noted previously in Table 3.2, the regulatory requirements for TOC range from a stringent limit of 0.1 mg/L in Singapore to TOC limits of 4 mg/L in Virginia. In addition, COD limits of 10 and 18 mg/L have been used in Virginia and Georgia, respectively, for surface water augmentation. The California TOC requirement of 0.5 mg/L, being considered for DPR projects, is less than the TOC concentration in nearly all drinking water supplies derived from the conventional treatment of surface waters. Furthermore, regulating to such an extremely low TOC level for advanced treated water may necessitate RO treatment without materially increasing public health protection. Trusselll et al. (2015) have reported that except for a select few contaminants that are difficult to remove by RO, AOP, or BAF, most trace organics present in wastewater are at concentrations not of concern to human health. A research study is currently underway by WRRF, to investigate the suitability of TOC as a surrogate and potentially recommend alternative approaches to ensuring the safety of advanced treated water relative to TrOCs. It is also worth to note that the above trace chemical criteria were not intended to preempt the regulatory decision-making process for permitting potable reuse projects; but were developed as guidelines to be used to evaluate proposed treatment train performance.

3.1.3. Use of multiple barriers to control of pathogens and chemical constituents

The multiple barrier concept, the cornerstone of the safe drinking water program, consists of coordinated technical, operational, and managerial barriers that help prevent contamination at the source, enhance treatment, and ensure a safe supply of drinking water for consumers. The multiple barrier concept is also fundamental to the practice of planned potable water reuse, to ensure the quality of the product water. In AWTFs, the multiple barrier concept is applied by linking together a number of independent, often redundant, unit treatment processes (barriers) to meet the treatment objectives with respect to the removal of pathogens and chemical constituents.

Typical log-reduction values granted for various unit treatment processes used in AWTFs are reported in Table 3.3. As shown in Table 3.3 no single treatment process can meet the log removal objectives specified in Table 3.2. However, significant protection is afforded when several independent barriers are combined in series. Thus, the failure of a single barrier does not result in the failure of the system. Further, the use of multiple barriers results in a high level of system reliability. The application of the values reported in Table 3.3 is illustrated in subheading 3.4 where the performance of advanced water treatment trains for pathogen log reduction is evaluated.

3.2. Advanced water treatment processes

In general, four types of treatment processes are utilized in advanced water treatment facilities: (1) processes used to remove particulate and colloidal constituents, (2) processes used to remove total dissolved solids (TDS) and the specific target constituents, (3) process used to assure disinfection of pathogens for the protection of public health, and (4) processes used to stabilize of final advanced treated water (ATW). Topics considered in this section with respect to technical and regulatory issues include: (1) public health consideration in potable water reuse, (2) representative advanced treatment trains used in potable water reuse, (3) the importance of source control, (4) upgrade to secondary wastewater treatment plant for potable water reuse, and (5) the use of environmental buffer for potable water reuse.

Table 3.3 Range of log reduction values for various unit treatment process reported in the literature. The values in parentheses are approved for groundwater augmentation projects in California

	Pathogen log removal values			
Process	**Virus**	***Cryptosporidium***	***Giardia***	**Total coliform**
Secondary treatment (activated sludge)	0-2 (1.9)	0-2 (1.2)	0-2 (0.8)	0
Secondary treatment (filtered and disinfected)	(5)	(0)	(0)	
Membrane bioreactor	0	0-4	0-4	0-3
Microfiltration (MF) or ultrafiltration (UF)	(0)	4 (4)	4 (4)	0-3
Ozone (O_3)	4-5	3	3	3
Nanofiltration	0-2	0-2	0-2	2-4
Reverse osmosis (RO)	(2)	(2)	(2)	2-4
Free chlorine disinfection following RO	(4)	(0)	(0)	0-3
Ultraviolet (UV) disinfection	2-4	2-4	2-4	3-5
Ultraviolet/hydrogen peroxide (UV dose ~ >900 mJ/cm^2)	4-6 (6)	4-6 (6)	4-6 (6)	
Advanced oxidation (UV dose ~ >900 mJ/cm^2)	4-6 (6)	4-6 (6)	4-6 (6)	
Subsurface application (6 months retention time)	(6)	(0)	(0)	
Surface water augmentation (6 months retention time)	(6)	(10)	(10)	

Source: Adapted from Olivieri et al., 2016; Philip Brandhuber, 2016.

3.2.1. Representative advanced treatment trains used in potable reuse projects

Multiple treatment trains have been used or proposed for potable water reuse projects. Several examples of treatment trains that are currently practiced for the production of ATW (e.g., purified water) in potable reuse projects are shown in Figure 3.1. As shown, the advanced water treatment trains can be operated with RO [see Figures 3.1(a) and 3.1(b)] and without RO [see Figure 3.1(c)] as will be further discussed below.

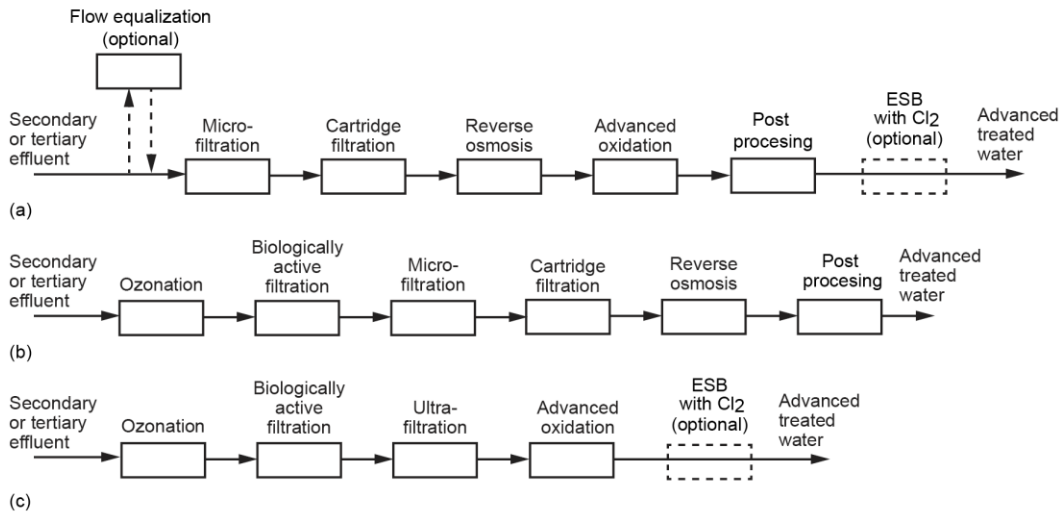

Figure 3.1 Examples of three successfully implemented treatment trains used in AWTFs for producing ATW: (a) RO based without ozonation and with optional ESB; (b) RO based without ESB and with ozonation and BAF; and (c) Non-RO based with ozonation, BAF, and ESB. (Source: Adapted from Tchobanoglous et al., 2015).

3.2.1.1. Treatment train processes with RO

The treatment train processes employed in Figures 3.1(a) and 3.1(b) uses RO treatment system. Except for optional engineered storage basin (ESB) with free chlorine, the treatment train shown on Figure 3.1(a) is representative of the process configuration employed currently by the Orange County Water District's (OCWD's) AWTF to produce ATW for groundwater augmentation (for additional detail information on OCWD IPR project see Kayhanian and Tchobanoglous, 2016). In the most recent expansion of the OCWD's AWTF, two large flow equalization tanks (each with the capacity of 28390 m^3) has been added before microfiltration to improve the long-term performance of the treatment train. The importance of flow equalization on treatment performance is discussed under Part 4.

The treatment train shown in Figure 3.1(b) is a modification of the treatment train shown in Figure 3.1a with the addition of ozone with biologically active filtration (BAF) to achieve additional oxidation and the biodegradation of constituents, gain disinfection credit, and improve MF performance. Another benefit of additional treatment is less reliance on other treatment processes for pathogen reduction and the potential reduction in size or need for the ESB (with or without free chlorine). The performance of the representative treatment trains with respect to the removal of pathogens and trace organic chemicals are discussed under subheadings 3.3.2 and 3.3.3, respectively.

3.2.1.2. Treatment train processes without RO

Because of cost and logistical issues associated with managing RO concentrate, especially in inland locations, interest exists in developing treatment trains capable of removing or converting chemical constituents without physically separating them from product water. The treatment train shown in Figure 3.1(c) eliminates the RO step, but employs ozone with BAF, UF, AOP, and the optional ESB with free chlorine. For example, the DPR system currently in use in the City of Windhoek, Namibia (for additional detail see Kayhanian and Tchobanoglous, 2016) does not use RO. The lack of TDS removal and a higher level of TOC in the effluent are the principal differences between the RO-based treatment trains shown in Figures 1a and 1b and the treatment train shown in Figure 1c. The TDS concentration of secondary-treated wastewater effluent often is 200 to 400 mg/L higher than potable water for a given system, due to the addition of salt as water is used domestically and discharged to the collection system. Consequently, depending on the TDS concentration of the community's main water supply and the percentage of potable reuse practiced, some TDS removal (i.e., by addition of NF or electrodialysis) may be required in treatment train system shown in Figure 3.1(c) to avoid elevated TDS concentrations.

3.3. Water quality values for representative advanced treatment trains

The water quality of ATW produced from the advanced treatment train can be evaluated through several water quality parameters including the removal of (1) conventional water quality constituents, (2) pathogens, and (3) specific trace organic and inorganic constituents.

3.3.1. Removal of conventional water quality constituents

For the purpose of comparison, representative water quality data derived from the advanced treatment trains shown in Figure 3.1 are reported in Table 3.4. As can be noted from Table 3.4, the overall quality of the water produced from different advanced treatment trains will vary depending on the processes included in the treatment train. Comparing the water quality from the three AWT treatment trains to the effluent from a convention activate sludge process with filtrations, the most pronounced differences are values related to solids concentrations, organics, nutrients, metals, and microorganisms. It is important to note that the data reported in Table 3.4, are presented for comparative purposes and are more qualitative than quantitative and should be used cautiously.

Table 3.4 Typical range of effluent water quality after various levels of advanced water treatment

Constituent	Unit	Untreated wastewater	Range of effluent quality for indicated treatment train			
			Conventional activated sludge with filtration	Figure 3.1(c)	Figure 3.1(b)	Figure 3.1(a)
TSS	mg/L	100-389	2-8	1-2	≤1	≤1
Turbidity	NTU	80-150	1-10	≤1	≤0.1	≤0.1
BOD	mg/L	133-400	<5-	≤1	≤1	≤1
COD	mg/L	339-1016	30-70	≤10-30	≤2-30	≤2-30
TOC	mg/L	109-328	15-30	2-5	0.1-1	0.1-1
NH_3-N	mg N/L	14-41	1-6	≤1	≤1	≤1
NO_3-N	mg N/L	0-trace	5-30	0.001	≤1	≤1
NO_2-N	mg N/L	0-trace	0-trace	≤0.001	≤0.001	≤0.001
Total N	mg N/L	23-69	80015-35	≤1	≤1	≤1
Total P	mg P/L	3.7-11	<MRL2-6	2-6	≤0.5	≤0.5
VOCs	μg/L	<100->400	10-40	≤1	≤1	≤1
Fe and Mn	mg/L	1-2.5	1-1.4	≤0.3	≤0.1	≤0.1
Surfactants	mg/L	4-10	0.5-1.5	≤0.5	≤0.1	≤0.1
TDS	mg/L	374-1121	374-1121	374-1121	≤5-40	≤5-40
Household chemicals	μg/L	10-50	5-30	≤0.1	≤0.1	≤0.1
Total coliform	No./100 mL	10^6-10^{10}	10^3-10^5	350	<1	<1
Protozoan cysts and oocysts	No./100 mL	10^1-10^3	0-10	≤0.002	≤0.002	≤0.002
Viruses	PFU/100 mL	10^1-10^8	10^1-10^4	≤0.03	≤0.03	≤0.03

Source: Adapted from Tchobanoglous et al., 2016.
Note: Household chemicals include: fire retardant, personal care products, and prescription and non-prescription drugs; AOP = advance oxidation process; BAF = biologically active filtration; MF = microfiltration; O_3 = ozone; PFU = plaque forming unit; RO = reverse osmosis; UV = ultraviolet

3.3.2. Log removal values for pathogens for representative advanced treatment trains

Expected pathogen log reduction credits for each of the three examples advance water treatment trains shown in Figure 3.1, derived using the data given in Table 3.3, are presented in Tables 3.5, 3.6, and 3.7, respectively. Note that the log reduction credits shown in these tables do not include pathogen reduction credits for the upstream WWTP or for the downstream drinking water treatment facility (DWTF) where the advanced treated water is blended upstream of the DWTF.

Table 3.5 Pathogen log reduction credits achieved by treatment trains shown in Figure 3.1(a)

Pathogen	Log reduction for different treatment technology				Total log reduction
	MF[a]	RO[b]	UV/AOP[c]	ESB with Cl_2 [d, e]	
Virus	0	2	6	4	12
Crytosporidium	4	2	6	0	12
Total Coliform[f]	3	2	6	4	15

Source: Adapted from Mosher et al. 2016.

[a] Four-log reduction of *Cryptosporidium* has been assumed for microfiltration (MF), based on credit commonly granted by various agencies for membranes passing daily membrane integrity tests.

[b] Two-log reduction of viruses, *Cryptosporidium*, and *Giardia* have been assumed for reverse osmosis (RO), based on credit commonly granted by various agencies for online monitoring of conductivity or total organic carbon.

[c] Six-log reduction of viruses and *Cryptosporidium* have been assumed for ultraviolet/advanced oxidation processes (UV/AOP).

[d] Per the U.S. EPA Surface Water Treatment Rule, free chlorine provides 4-log virus inactivation at a CT of 6 mg/L-min at 10 °C.

[e] Both chlorine (and ozone) likely will achieve higher log reduction values than shown if higher CTs are used.

[f] Actual demonstrated values (Gerringer et al., 2015).

Table 3.6 Pathogen log reduction credits achieved by treatment trains shown in Figure 3.1(b)

Pathogen	Log reduction for different treatment technology					Total log reduction
	O_3[a]	BAF	MF	RO	UV/AOP	
Virus	4	0	0	2	6	12
Cryptosporidium	0	0	4	2	6	12
Total Coliform[b]	2-4	0	3	2	6	>13

Source: Adapted from Mosher et al., 2016

[a] Per the U.S. EPA Surface Water Treatment Rule, ozone provides 4-log virus inactivation at a CT of 1 mg/L-min at 10 °C.

[b] Actually demonstrated values (Gerringer et al., 2015).

Table 3.7 Pathogen log reduction credits achieved by treatment trains shown in Figure 3.1(c)

	Log reduction for different treatment technology					Total log reduction
	O_3[a,b]	BAF	UF[c]	UV/AOP [d]	ESB with Cl_2[e]	
Virus	4	0	2	6	4	16
Cryptosporidium	0	0	4	6	0	10
Total Coliform[f]	2-4	0	3	6	4	>15

Source: Adapted from Mosher et al., 2016

[a] Per the U.S. EPA Surface Water Treatment Rule, ozone provides 4-log virus inactivation at a CT of 1 mg/L-min at 10 °C.

[b] Both chlorine (and ozone) likely will achieve higher log reduction values than shown if higher CTs are used.

[c] Two-log reduction of viruses has been assumed based on MS-2 phage challenge testing conducted by ultrafiltration (UF) module manufacturers under National Science Foundation (NSF) Enviro. Tech. Verification and California Title 22 Certification Programs.

[d] Six-log reduction of viruses and *Cryptosporidium* have been assumed for UV/AOP based on testing by UV manufacturers.

[e] Per the U.S. EPA Surface Water Treatment Rule, free chlorine provides 4-log virus inactivation at a CT of 6 mg/L-min at 10 °C.
[f] Actually demonstrated values (Gerringer et al., 2015).

As reported in Tables 3.5, 3.6 and 3.7, all three treatment trains presented in Fugue 3.1 provide significant removal of pathogens and meet the log-reduction criteria established in California and Texas. Treatment trains shown in Figures 3.1(a) and 3.1(b) provide more removal of *Cryptosporidium* than treatment train shown in Figure 3.1(c) (12 log versus 10 log), but treatment train shown in Figure 3.1(c) provides more removal of viruses than treatment trains in Figures 3.1(a) and 3.1(b) (16 log versus 12 log). Virus removal for treatment train in Figure 3.1b could be increased to 16 log with the addition of free chlorine disinfection (without an ESB), which could be provided inexpensively. If higher contact times (CTs) were used, both chlorine and ozone could consistently achieve higher log reductions than shown in Tables 3.5 and 3.7.

3.3.3. Trace chemical constituent values for representative advanced treatment trains

The concentration of trace chemical constituent treated by different individual advanced water treatment process is shown in Table 3.8. As shown, no one treatment process removes all chemical contaminants, so maintaining multiple barriers is essential. Rejection by RO of small, polar compounds (such as NDMA) is low (Plumlee et al., 2008), as is that of low molecular weight non-ionic, hydrophilic compounds, including the DBPs chloroform and bromoform (Drewes, 2002). Alternative compounds, such as flame retardants [e.g., tris(2-carboxyethyl) phosphine (TCEP)], are resistant to AOPs (Plumlee et al., 2008).

The removal of all regulated and unregulated chemicals, as with the removal of pathogens, requires multiple treatment barriers such as those shown in Figure 3.1. All three potable reuse treatment trains shown in Figure 3.1 provides sufficient multiple barriers (i.e., 2 or more multiple barrier) for the removal TrOCs and other chemical contaminants. For instance, the RO-based treatment trains shown in Figures 3.1(a) and 3.1(b) can reliably meet California's current requirements for potable reuse and can effectively reduce TrOCs as demonstrated for many years at the Groundwater Replenishment System in Orange County, California.

Table 3.8 Concentration of elective trace constituent of effluent treated by different conventional and advanced treatment processes compared with their treatment criteria

Trace constituent	Concentration (ng/L)								
				Advanced treatment technology					
	Treatment criteria	MRL	Secondary effluent	O3 effluent	BAF effluent	UV effluent	MF filtrate	RO permeate	UV/H2Of efluent
Alcohol	400	31	292	<MRL	<MRL	<MRL	NT	<MRL	<MRL
Carbamazepine	10,000	1	194	<MRL	25	1	T	<MRL	<MRL
DEET	200,000	6	45	<MRL	<MRL	<MRL	NT	<MRL	<MRL
Estrone	320	1	<MRL	<MRL	<MRL	<MRL	NT	<MRL	<MRL
Meprobamate	200,000	3	380	158	178	170	NT	<MRL	<MRL
PFOA	400	9	12	10	35	22	NT	<MRL	<MRL
PFOS	200	8	<MRL	<MRL	<MRL	<MRL	NT	<MRL	<MRL
Primidone	10,000	7	4,100	525	23	186	NT	7	75
Sucralose	150,000,000	77	24,800	17,200	19,700	21,700	NT	<MRL	<MRL
TCEP	5,000	77	<MRL	<MRL	<MRL	<MRL	NT	<MRL	<MRL
Triclosan	2,100,000	8	128	<MRL	<MRL	9	NT	<MRL	<MRL

Source: Adapted from Tchobanoglous et al., 2016
Note: BAF = biologically active filtration; DEET = N,N-diethyl-meta-toluamide or diethyltoluamide; MF = microfiltration; MRL = method reporting limit; NT = not tested; PFOA = perfluorooctanic acid; PFSO = perfluorooctane sulfonate; RO = reverse osmosis; TCEP = tris (2-Carboxyethyl) phosphine) hypochloride; UV = ultraviolet.

In most cases, the treatment train shown in Figure 3.1(c) could not reliably meet California's TOC limit (0.5 mg/L), although the suitability of this low regulatory limit is questionable and is currently under investigation. However, the treatment trains shown in Figure 3.1c could be easily modified to incorporate GAC downstream of the biological filtration process by designing dual filtration contactors to further improve the removal of trace chemical contaminants (Schimmoller, 2016).

3.4. Environmental buffers for potable reuse

The principal distinction between IPR and DPR systems, as noted previously, is related to the utilization of an environmental buffer. In IPR systems, the advanced treated water is introduced into a natural environmental buffer for an extended period of time before being withdrawn for drinking water use. Environmental buffers most commonly used in IPR systems include groundwater and surface water augmentation (e.g., reservoir). For DPR systems, the utilization of a natural environmental buffer is not required and only, if needed, is an engineered storage buffer used.

3.4.1. Groundwater (GW) augmentation

When using GW as an environmental buffer, ATW is recharged into groundwater aquifer by surface spreading and direct injection. The treatment trains used may vary depending on the recharge augmentation system, but advanced treatment is required for both types of groundwater recharge application. Generally, surface spreading is accomplished in large bermed basins with sand or permeable soil above an unconfined aquifer where reclaimed water can percolate into the subsurface. The recharge water in spreading basins can be a mixture of reclaimed water and local stormwater runoff. With direct injection method, ATW is injected through subsurface wells into groundwater aquifer. Compared with surface spreading, direct injection usually requires more advanced treatment of reclaimed water for two reasons: (1) to reduce the potential for subsurface clogging, and (2) to compensate for the lack of soil aquifer treatment. Some form of direct injection or managed aquifer recharge has been successfully applied in California for almost 50 years and is the sources of drinking water supply for close to 60 percent of population in Los Angeles.

Several states have developed regulations for groundwater augmentation. Perhaps the most stringent are those adopted by California. Some of the key requirements of California regulation are reported in Table 3.9. As reported in Table 3.9, the degree of treatment requirements varies with the type of application method used for groundwater recharge. It is also important to note that the requirements listed in Table 3.9 are related primarily to the quality of the wastewater and that many other requirements must be met including those dealing with the amount of water that can be spread, the development of an operational plan, monitoring and reporting requirements. Using the requirements set forth in Table 3.9, if satellite wastewater reclamation facilities were developed in Iran, surface spreading could be used initially. With the development of AWTFs direct injection could also be used to help recover the deep aquifer.

Table 3.9 Key requirements for groundwater augmentation with various levels of treated wastewater in California

Item	**Description**
Recharge method and the level of treatment requirements	
Recharge application method:	***Required treatment level:***
Surface spreading with advanced wastewater treatment	Oxidation[a], filtration, disinfection, soil aquifer treatment
Surface spreading with	Oxidation, reverse osmosis, advance oxidation, soil aquifer treatment
Injection with advanced treated water	Oxidation, reverse osmosis, advance oxidation process
Water quality requirements and the level of contaminants removal required	
Water quality requirements:	**Required contaminant removal:**
Overall pathogen reduction[b]	≥ 12-log virus, ≥10-log *Giardia* cyst, ≥10-log *Cryptosporidium* oocyst
Drinking water MCLs	All except nitrogen
Drinking water action levels	Lead and copper
Total nitrogen	≤ 10 mg/L, nitrogen limit can be met in recycled water or combination with other diluent water
Total organic carbon in mg/L	TOC ≤ 0.5/Recycled water contribution (RWC)
Other conditions and requirements:	
Raw water quality	Industrial pretreatment and source control program
Virus reduction	1-log credit per month of subsurface retention
Giardia and *Cryptosporidium* reduction	10-log each for disinfected tertiary effluent with at least 6 months subsurface retention

[a]The term "oxidation" is defined as a wastewater in which the organic matter has been stabilized, is non-putrescible, and contains dissolved oxygen (i.e., essentially effluent from secondary treatment)

[b]The overall pathogen treatment requirement can be met either by advanced water treatment or a combination of wastewater treatment and treatment achieved in the subsurface as a function of the retention time. Minimum treatment requirements that must be met with treatment processes before spreading can occur are also specified.

Note: RWC = recycled water contribution

3.4.2. Surface water (SW) augmentation

Using surface water as the environmental buffer ATW is blended with surface water before being extracted and sent to a drinking water treatment plant (DWTP). Surface water storage provides a mitigation response time in the event of process failure and could also provide some additional treatment. However, the effectiveness of treatment depends on the effluent quality of the reclaimed water, and the water quality and environmental conditions of the surface water (Tchobanoglous et al., 2015). Planned augmentation of a surface water source with reclaimed water has been practiced in Fairfax County, VA, since 1978 (https://www.uosa.org/IndexUOSA.asp).

As with groundwater augmentation, several states have developed or are in the process of developing regulations for surface water augmentation. California adopt surface water augmentation requirements in 2017. In many respects, the overall pathogen reduction requirements remain the same as those for groundwater augmentation. The biggest difference is in residence time and the mixing requirements. The minimum required specifications for theoretical retention time for a reservoir should be no less than 180 days. As for the mixing requirement, the volume of water withdrawn from the augmented reservoir for human consumption should contain no more than one percent recycled municipal wastewater by volume during any 24-hour period. The mixing can be increased to ten percent by volume, if recycled municipal wastewater is subjected to additional treatment by producing no less than a 1-log reduction of enteric virus, *Giardia* cysts and *Cryptosporidium* oocysts.

3.5. Engineered storage buffer in DPR

Engineered storage basin is generally used in place of an environmental buffer in DPR system. The purpose of an engineered storage buffer (ESB) in DPR systems is to retain any off-spec water, resulting from a plant or treatment process failure, and, thus, avoid or minimize the discharge of off-spec ATW to a drinking water treatment plant (DWTP) or the drinking water distribution system. In general, the sizing of an ESB depends on the maximum time from when a failure occurs in the treatment system to when the system has been corrected such that the quality of the final product water is no longer affected. Several configurations can be used for ESB including plug flow pipelines, baffled tanks, or tanks in parallel operated in a fill, store, and draw mode (Tchobanoglous et al., 2011).

With proper control and residual monitoring, chlorination or ozonation can be used in conjunction with an ESB to provide further treatment for the off-spec ATW which may contain pathogens (Tchobanoglous et al., 2015). In some locations, additional upstream treatment in lieu of an ESB may be desirable because of the large footprint requirements and hydraulic constraints associated with ESBs, especially for treatment plants of significant size. It should be noted that some agencies feel that, placement of ATW into an ESB provides essentially no water quality improvement, and, may in fact, deteriorate ATW water quality by exposure to potential environmental. Where ATW can be produced with proven performance and reliability and the quality can be validated rapidly, the application of DPR without ESB can be justified. Further, some agencies feel that blending ATW with other water before treatment in a water treatment facility provides adequate barrier for the protection of public health. For example, two of the current DPR systems used in Big Spring in Texas and the City of Windhoek in Namibia do not use an ESB.

Part 4: Source control and enhanced wastewater treatment for non-potable and potable reuse applications

When treated wastewater effluent is to be treated further for non-potable and potable reuse applications, the objective of wastewater treatment should be to produce the highest quality effluent possible for further treatment for potable reuse (Tchobanoglous and Leverenz, 2019). Two important measures that can be taken to enhance the quality of the treated wastewater which will treated further for potable reuse are: (1) development and implementation of an effective source control program and (2) optimization of wastewater treatment facilities, both existing and new. It must be stressed that the two measures discussed in this part should be implemented even if a potable reuse program is not being considered. With these measures in place all forms of reuse can be realized in the future.

4.1. Development and implementation of source control programs

The major source of water in a water reuse project is the reclaimed water that is generally generated from municipal communities. The primary sources of wastewater generated in a municipal community are from residences and commercial, institutional, and public facilities. In addition, depending on the community, significant volume of wastewater may also be generated from industrial complexes. The organic and inorganic constituents contained in wastewater and the presence of constituents of concern from each of the indicated sources can vary significantly. To control, limit, or eliminate the discharge of selective constituents from various sources into wastewater—that are difficult to treat or impair the final quality of treated wastewater intended for potable reuse (PR)—is usually accomplished through source control. The benefits of source control, the principal components of a source control program, and realistic expectations are considered below. The development of a source control programs in Iran is considered in Section 4.2.

4.1.1. Benefits of source a control program

The source control is usually accomplished before specific pollutants are discharged into the wastewater collection system prior to reaching secondary wastewater treatment facilities. Keeping constituents of concern (COCs) out of the wastewater system through a robust source control program can be the most beneficial, efficient, and cost-effective strategy for managing and treating wastewater for reuse application. The principal benefits of an effective source control program include:

- Minimize the discharge of potentially harmful or difficult-to-treat chemical constituents to the wastewater collection system from homes, commercial businesses, and possibly from industries and health care facilities.
- Improve wastewater effluent quality for advanced water treatment.
- Provide the public with confidence that the wastewater collection system is being managed with potable reuse in mind.

4.1.2. Principal elements of a source control program

An effective source control program usually contains multiple elements that include: (1) regulatory authority; (2) monitoring and assessment of the wastewater collection system within the service area; (3) investigation of chemical and other constituent sources; (4) maintenance of the chemical constituents' inventory; (5) preparation of a public outreach and participation program; and (6) preparation of a response plan for water quality deviations. These elements are considered further in Table 4.1. Source control program expectations and some example source control projects are discussed below.

Table 4.1 Description of major elements for an enhanced source control program in a potable reuse program

Element	Description
Regulatory authority	
Legal authority	Ensure that the source control program has sufficient legal authority to develop and control source control measures, including authority to oversight/inspection as well as plan and review new connection to the collection system.
Discharge permit	Ensure that industrial discharge permit and other control mechanisms can effectively regulate and reduce the discharge of COCs.
Enforcement	Ensure that the enforcement response program can identify and respond rapidly to COCs.
Alternative control programs	Consider alternative control mechanisms, such as BMPs or self-certification for zero discharge of pollutants for classes of industries or commercial businesses.
Monitoring and assessment of the wastewater collection system in service area (sewershed)	
Routine monitoring program	The influent to the WWTP and secondary or tertiary effluent to the AWTF are monitored routinely for regulated constituents and other COCs that may be discharged into the collection system service area.
Constituent prioritization program	COCs are identified and short-listed using results from the routine monitoring. It may be necessary to develop separate monitoring program for the constituents of greatest concern.

Evaluation of technically based local limits	Regulated constituents and other COCs are evaluated for their potential to cause interference, pass through an AWTF, or affect human and environmental health and safety. For the development of local limits, consider including a broader spectrum of COCs such as (1) regulated and non-regulated constituents that are relevant for PR (e.g., drinking water contaminants) or (2) CESs.
Source investigation	
Industrial and commercial business inventory	Develop and maintain a frequently updated, comprehensive inventory of industries and businesses that may use products for chemicals containing COCs or generate intermediate COCs. For agencies with large service areas, multiple communities, or industrial flows coming from other wastewater entities, it may be desirable to link the inventory to a service area mapping tool such as a geographic information system (GIS) network.
WWTP-AWTF joint response plan	The response plan includes a flow chart showing key responsibilities and decision points to either investigate or mitigate COCs being discharged into the collection system.
Maintenance of current inventory of chemicals and constituents	
Chemical inventory program	Develop and maintain a database of the chemicals stored and inventory volumes used annually by industrial and commercial producers and manufacturers in the service area. Potential sources of this type of information include the industries themselves or local fire department.
Waste hauler monitoring program	A program is needed to monitor, and track discharges of septic wastes or other wastewater delivered to the collection system by truck. Haulers should be permitted and required to provide chemical inventory and discharge information to the wastewater treatment authority before being allowed to discharge. Consideration should be given to requiring waste haulers to deliver to a different treatment facility.
Chemical fact sheet	Maintain a database of fact sheets for CECs encountered within the service area.

Element	**Description**
Public outreach program	
Industrial discharges	Provide: (1) public outreach information on PR to industries, (2) source control practices, and (3) compliance assistance and permit assistance to support the PR program. Develop a program that encourages commercial and industrial discharges to be partners in protecting the sewershed, such as environmental stewardship programs or award programs for consistent compliance Assist and encourage industries and business that use chemicals that contain COCs to identify source control options, such as chemical substitution.
Service area pollution prevention partnership program	Develop a cooperative program with cities, counties, or other jurisdictions within the WWTP service area to disseminate information to the public about COCs and acceptable discharges to the sewer.
Public education and outreach program	Provide outreach to the public regarding the proper disposal of pharmaceuticals and household products containing chemicals that may be difficult to treat (e.g., what to flush and not flush). Consider developing a household hazardous waste collection program.
Education program	Develop school educational programs for grades 1 through 12 that address source control issues related to portable reuse.

Response plan for identified constituents	
Interagency collaboration	The success of a source control program will depend on strong interagency cooperation and responsiveness between the WWTP and AWTF. For PR project that receive industrial waste from outside the service area, ensure that the agreement to accept the waste is consistent with source control program requirements. For PR projects where the agency that administers the source control program is not the agency that operates the AWTF, consider entering into a memorandum of understanding or other contractual agreement so that appropriate source control actions can be taken. If necessary, to protect water quality.
Response to water quality deviations	Develop an action plan for responding to water quality deviations. For example, if a specific chemical constituent is detected at the AWTF, review operation and calibration records for online meters and any analytical methods that may be involved. If a problem is not identified, then notify the WWTP to initiate a review and inspection of the WWTP for possible sources of the constituent. If no source is found at the WWTP, then initiate a wastewater collection system sampling. If a problem is identified, the action plan should include procedure for the operations staff to notify the source control staff to respond to and correct the issue and if necessary, procedures for bypassing or shutting down the facility.

Source: Adapted from Tchobanoglous et al., 2015.
AWTF = advanced water treatment facility; BMPs = best management practices; CEC = constituent of emerging concern; COCs = constituent of concerns; PR = potable reuse; WWTP = wastewater treatment plant; GIS = geographic information system

4.1.3. Realistic expectations from a source control program

Source control programs are not designed to remove all unwanted constituents and hence the expectations must be realistic regarding their effectiveness. The most important expectation should be based on the reduction of problematic constituents. The successful reduction of problematic constituents typically occurs when: (1) the constituent is found consistently at measurable levels in the wastewater influent or collection system, and (2) the contributing sources is through a single source or a group of similar sources accounting for most of the influent loading.

4.2. Developing a source control program in Iran

In developing effective source control programs in Iran, it is essential to understand the sources of toxic compounds entering the wastewater collection system from readily managed point sources. To minimize the impact from large industrial dischargers, consideration should be given to diverting highly industrialized discharges to alternative treatment facilities. Hence, as part of the PR program in Iran, the Iranian authority may only consider wastewater collected from municipal sector and exclude wastewater generated from industrial sources. However, when the wastewater from industrial sources cannot be excluded and must be discharged into the municipal wastewater collection system and delivered to the water reclamation facility, the authorities should consider implementing an industrial pretreatment program similar to the National Pretreatment Program established by the U.S. EPA (APAI, 2015).

Several successful source control programs such as "No Drugs Down the Drain" programs, drug take-back programs, and household hazardous waste collection programs have been developed by water agencies in the United States that could be adapted and used in Iran. Some agencies have enhanced pretreatment program elements to augment their pollution prevention efforts. Excellent examples of highly sophisticated source control programs include those developed by the Orange County Sanitation District (www.ocsd.com/Home/ShowDocument?id=10403;www.ocsd.com/residents/information/source-control), the City of San Diego, (https://www.sandiego.gov/public-utilities/sewer-spill-reduction) and the Water Environment Research Foundation (WERF) Tool to Measure Source Control Program Effectiveness (https://www.casqa.org/sites/default/files/effectiveness_assessment/rl-12_werftoolseffectiveness98wsm2.pdf).

4.3. The role of secondary treatment in non-potable and potable reuse applications

Historically, most wastewater treatment plants are designed to produce an effluent that can be discharged to the environment. However, as greater emphasis is placed on non-potable and potable reuse, it will become important to rethink conventional wastewater treatment.

4.3.1 Conventional wastewater treatment

Typically, the objective of conventional secondary wastewater treatment facilities is to produce an effluent that is suitable for dispersal to the environment, subject to specific discharge requirements (see Figure 4.1). To meet this objective, municipal wastewater treatment plants are operated to: (1) remove coarse and settleable constituents, (2) transform dissolved and particulate biodegradable constituents into acceptable end products, (3) incorporate suspended and non-settleable colloidal solids into a biological floc or biofilm, (4) transform or remove of nutrients, such as nitrogen and phosphorus, (5) transform or remove trace organic constituents (TOrCs), and (6) remove pathogenic microorganisms (Asano et al., 2007; Tchobanoglous et al., 2014).

However, if the treated effluent is to be the source water for advanced wastewater treatment, it is reasonable to conclude, based on actual plant experience that changes should be made to the design and operation of existing and proposed new wastewater treatment plants to produce an effluent that is optimized with respect to treatment an advanced water treatment facility. As discussed below, conventional wastewater treatment must be rethought.

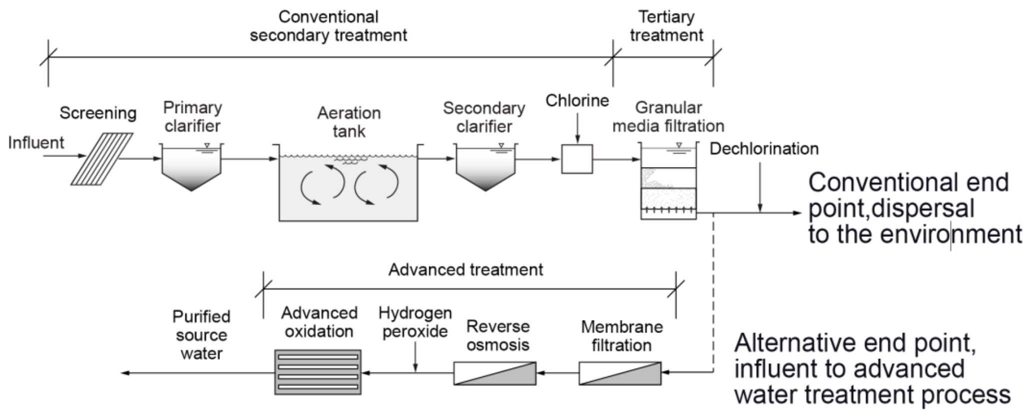

Figure 4.1 Generalized secondary wastewater treatment process treatment train with conventional and alternative end points for the treated effluent (a) conventional dispersal to the environment and (b) as an influent source water for advanced water treatment for reuse applications (*Source:* Tchobanoglous et al., 2011).

4.3.2. Rethinking secondary treatment

To improve the performance of existing wastewater treatment plants with respect to water reuse, a number of treatment plant upgrades and operational changes can be made. Upgrading secondary treatment trains to produce higher effluent quality will generally provide several benefits including: (1) enhanced AWTF treatment efficiency, (2) reduced energy and carbon footprint, and (3) consistent regulatory compliance. For example, certain constituents, such as pathogens, chemicals of emerging concerns (CECs), and disinfection byproduct (DBP) precursors, may be removed more cost effectively through improved conventional secondary biological treatment process. Some important measures that can be taken to improve treatment performance and enhance the reliability and quality of the effluent of existing and any future proposed wastewater treatment in Iran are discussed in the following section.

4.4. Measures to enhance the performance of secondary treatment facilities

Most conventional wastewater treatment processes, including those in Iran, employ some form of biological treatment, most commonly the activated sludge (AS) process. A typical flow diagram of a conventional biological wastewater treatment process, employing the AS process, is as shown in Figure 4.1. For example, as noted previously in Sections 4.1 and 4.2, the establishment of an effective source separation program prior introducing the wastewater into secondary wastewater treatment plants is one of the first steps that can be taken to enhance the quality of the treated effluent. With an effective source control program in place, some important measures that can be made to enhance the performance of existing and proposed new wastewater treatment plants for water reuse applications. The implications of the measures identified in Table 4.2 are considered below.

Table 4.2 Measures that could be employed to improve the treatment performance and enhance the reliability of existing and proposed WWTPs in Iran

Measure	**Value of each measure**	**Comments**
Influent flowrate and load equalization	Efficiency, water quality, reliability	• Enhance biological treatment by: (1) reducing or eliminating shock loadings, (2) diluting inhibiting substances, (3) improving performance of overall biological treatment processes through improved consistency in solids, organics, and nutrient loading. • Biological treatment reactor sizes can be reduced with flow equalization. • Blower aeration and return flow rates and process controls are stabilized—requiring only minor adjustments—with flow equalization. • Surface area requirements for secondary effluent filtration are reduced and filter performance is improved with more consistent filtered water quality and uniform filter-backwash cycles.
Enhanced preliminary treatment	Efficiency, reliability	• Removal of inert constituents that can improve treatment performance (e.g., rags and plastic materials). • Alteration of wastewater particle size distribution, which will enhance biological treatment kinetics
Primary effluent filtration	Efficiency, reliability	• Enhanced recovery of organic constituents. • Alteration of wastewater particle size distribution, which will enhance biological treatment kinetics
Alternative primary treatment	Efficiency, reliability	• Enhanced recovery of organic constituents. • Alteration of wastewater particle size distribution, which will enhance biological treatment kinetics
Elimination (or equalization) of untreated return flows	Water quality, reliability	• Return flows are generated from solids thickening and dewatering process. • All solids handling processes involve significant amounts of polymer to enhance dewatering process; some polymers have been identified as precursors to the formation of some disinfection byproduct (DBPs), such as N-nitrosodimethylamine (NDMA).
Modification of operational mode for biological treatment process	Water quality, reliability	• To enhance performance of AWTF, non-nitrifying biological treatment processes should be operated in nitrification/denitrification mode. • Longer mean cell residence times can be used to remove nitrates and enhance removal of trace organic chemicals and other specific constituents, such as metals.
Effluent filtration and disinfection	Water quality, reliability	• Effluent filtration improves the operation of advanced water treatment facilities • Disinfection practice must be coordinated with the technologies and mode of operation used for advanced water treatment

Improved process monitoring and control	Water quality, reliability	• Enhance monitoring of individual processes to improve performance. • Specific studies of new process monitoring equipment and techniques • Facility should evaluate online meters for maintaining solids inventory, in addition to monitoring effluent water quality with turbidity and conductivity monitors. • A meter maintenance procedure must be in place, with dedicated staff to ensure that meters are calibrated properly and checked periodically with laboratory measurements and action points are identified (a flow chart of responsibility is also necessary).

Source: Adapted from Tchobanoglous et al., 2015

Efficiency=recommended improvement increases overall cost efficiency of operation; water quality= recommended improvement increases final potable water quality; reliability = recommended improvement increases overall reliability of treatment train; AWTF = advanced water treatment facility; mm = millimeter; WWTP = wastewater treatment plant.

4.4.1. Flowrate and load equalization

In the future, it is possible for Iran to consider replacing the existing conventional activated sludge processes with the newer and more efficient membrane bioreactors (MBRs). Because the performance of MBRs is susceptible to inflow flowrate fluctuations, flowrate equalization is generally required. Individual membrane equipment manufactures employ their own sizing criteria, which will typically include the duration and magnitude of peak and average daily flowrate. In general, for an MBR to perform efficiently, the peak flowrate should be limited to 1.5 times the average flowrate. In most application, the peak flowrate will be a key factor in determining the selection of the type of membrane system and the number of modules required. In some cases, load equalization may also be required.

4.4.2. Enhanced preliminary treatment

Improved coarse screening, typically two-stage, will help in the removal of rags and plastic materials that hamper downstream processes. The implementation of two-stage coarse screening will involve expanding the headworks to accommodate the additional equipment and storage facilities. Perhaps even more significant is the implementation of effective grit removal facilities. More effective grit removal will eliminate downstream accumulations in aeration tanks and anaerobic digesters, a common occurrence. The key to effective grit removal is to recognize that the specific gravity of grit in wastewater collection systems is about 1.3 to1.4 and not 2.65 as commonly used in older environmental engineering textbooks. Modern grit removal practice is discussed in Tchobanoglous et al., 2014.

4.4.3. Primary effluent filtration

At the name implies primary effluent filtration (PEF) involves the filtration of settled primary effluent. Currently there are a number of filter technologies that can be used for PEF. The principal advantages of PEF are: (1) reduced power consumption for aeration, (2) increased biological treatment efficiency due to the alteration of the particle size discharged to the biological process, (3) reduced variability in the organic loading to the biological treatment process, and (4) enhanced energy recovery due to the removal of organic matter from settled primary effluent.

4.4.4. Alternative primary treatment

In the future, concern with energy savings and carbon footprint reduction, will force municipalities to be creative and use treatment technologies that address these issues. Several new alternative technologies are now in use or underdevelopment. One such technology involves the use of filtration process employing a cloth filter as a replacement for primary sedimentation (see Figure 4.2).

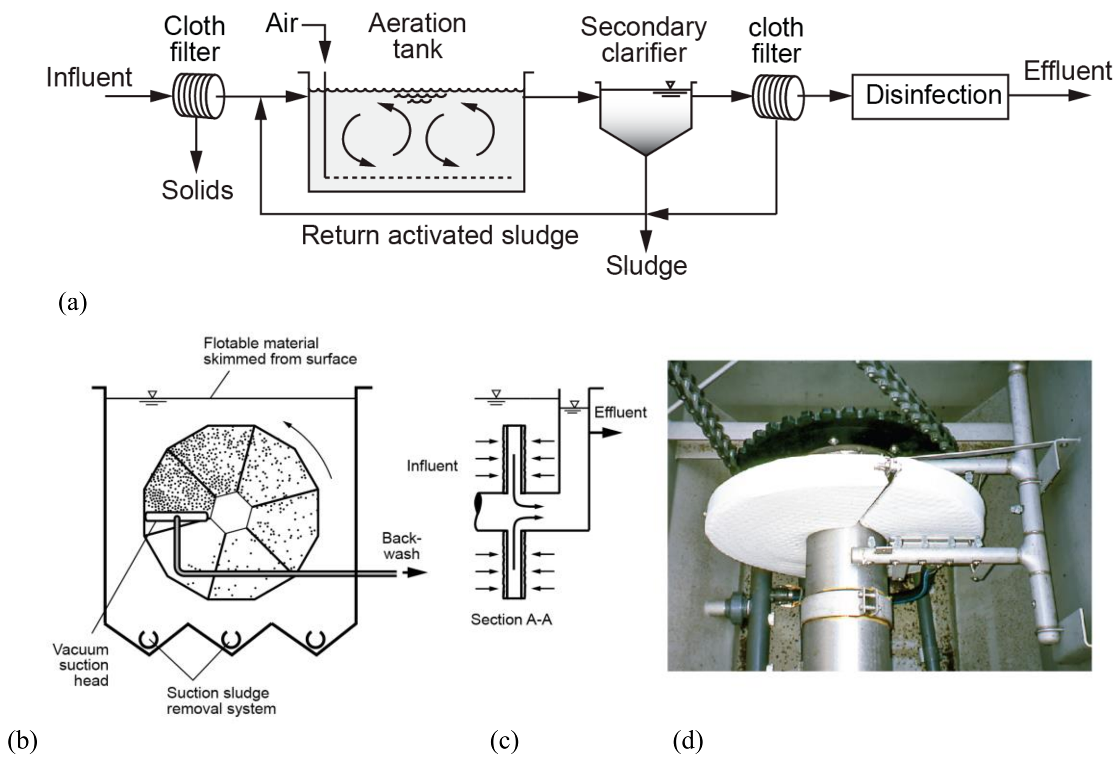

Figure 4.2. Use of cloth filters in wastewater treatment:(a) treatment process flow diagram illustrating the use of cloth filter as a replacement for primary sedimentation and for effluent filtration, (b) schematic of cloth filter with vacuum suction for the removal of accumulated solids, (c) cross section through filter disk, (d) view of single disk cloth filter. (Adapted in part from Tchobanoglous et al., 2014).

The principal advantages of the cloth filtration process are that (1) it requires 1/5 the space of conventional primary clarifiers, (2) provides better performance, and (3) is more cost-effective. Additional benefits include: (1) increase in biological treatment efficiency due to the alteration of the particle size discharged to the biological process, (2) reduced power consumption for aeration power, (3) decrease in aeration treatment basin volume requirement, (4) reduction in aeration basin mixing power requirements, (5) increase in secondary treatment capacity, and (6) increased digester biogas energy production due to the higher removal of organics from the raw wastewater. The cloth filter is also used for effluent filtration. A flow diagram for an upgraded activated sludge process employing the cloth filters is shown in Figure 4.2(a).

4.4.5. Reducing or eliminating untreated return flows

In the treatment of wastewater, liquid streams are produced from the separation of water from primary, secondary, combined, or from digested sludges during solids processing. The term "return flows," is used to describe these liquid streams which have chemical characteristics that prevent their direct discharge with the wastewater treatment plant effluent. Unfortunately, return flow streams can contain polymers used for sludge dewatering, soluble organic nitrogen compounds, ammonium, insoluble inorganic compounds and a variety of other compounds. Current practice at most wastewater treatment plants is to recycle these return flows to the head of the plant or directly to the secondary process for treatment, typically during the daytime hours. However, because these return flows contain constituents that can impact the performance of the secondary treatment process significantly as well as advanced AWTFs, it has become increasingly clear that they must be managed more effectively.

One approach that has been used to mitigate the impact of these return flows is to provide flow equalization, with discharge to the plant flow during the early morning hours when greater assimilative capacity is available. If the primary sedimentation basins are replaced with cloth filters, as discussed above, the primary sedimentation can be repurposed as flow equalization basins. In large wastewater treatment plants, and especially those where the treated effluent is subject to stringent discharge requirements or is to be processed further for PR, the trend is to provide separate treatment facilities for the return flow streams. It is anticipated that this trend will increase in the future. In some locations, the problem of return flows is eliminated by providing scalping wastewater treatment plants which extract wastewater from a nearby collection system, treat it, and reuse it locally. In such plants, all return flows are discharged to the collection system for downstream treatment at a centralized facility (see Part 5).

4.4.6. Modification of treatment process operating mode

Modification of the biological treatment mode can have a significant effect on the unit operations in the AWTFs. For example, converting to enhanced nitrification and denitrification is especially beneficial when membrane filtration is used in AWTF. It has been demonstrated that fouling rates for a UF membrane increased by a factor of nearly 10 if the biological treatment process was operated in a non-nitrifying or conventional mode. The observed fouling condition was attributed largely to colloidal organics greater than 10,000 Daltons (Salveson et al., 2012). Denitrification also has the added benefit of reducing the degree of nitrate removal that must be achieved in the AWTF. As an example, the OCWD GWRS was initially using non-nitrified secondary effluent from OCSD. However, since 2010, OCSD completed operational changes to enable its facility to produce a nitrified effluent from the activated sludge process. At present the OCWD GWRS feed water is comprised approximately 80% activated sludge that include nitrification/denitrification and 20% trickling filter effluent. These operational changes resulted with a significant reduction (up to 50%) in the fouling rate (measured as resistance, 1/m) of the full-scale MF system (see Figure 4.3). Based on the documented improved performance of the membrane processes, as illustrated in Figure 4.3, if existing wastewater treatment plants are to be used to produce effluent for further processing in an AWTF for PR, nitrification/denitrification should be implemented.

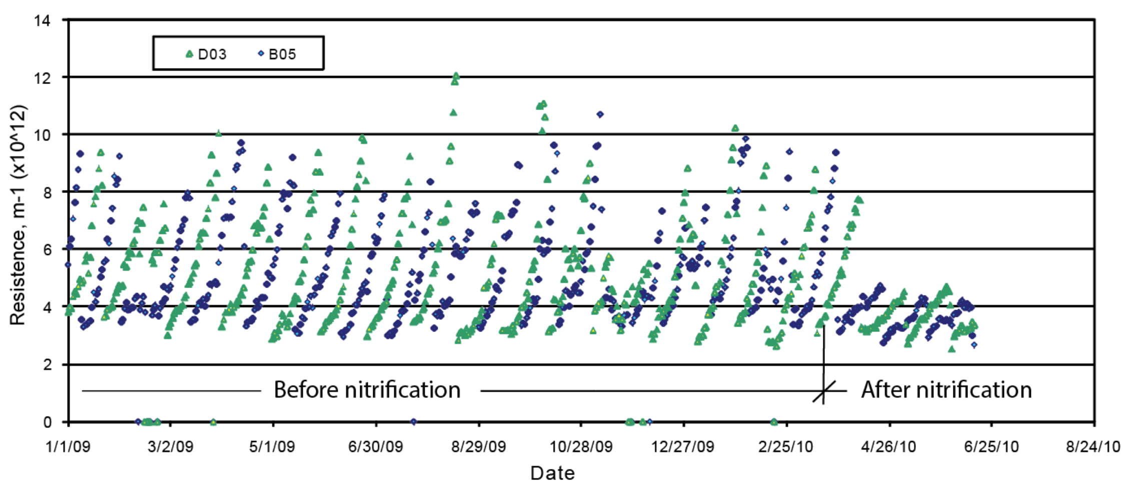

Figure 4.3 Observed membrane fouling, measured as resistance (1/m), at OCWD GWRS before and after wastewater treatment plant switched to nitrification mode of operation March 2010 (*Source:* Tchobanoglous et al., 2015).

4.4.7. Effluent filtration and disinfection

Effluent filtration, often considered a tertiary treatment process (see Figure 4.1), is especially important as a pretreatment step where micro or ultrafiltration is used in the AWTF. Not only does effluent filtration reduce the organic loading on downstream treatment processes, it helps eliminate turbidity spikes that often occur in secondary treatment processes.

Disinfection practice, including technologies and disinfection agents employed, must be coordinated with the technologies and mode of operation used for advanced water treatment.

4.4.8. Enhanced process monitoring and control

In addition to the process and operational changes discussed above, any wastewater treatment plant designed and operated to produce treated effluent for PR can benefit from enhanced monitoring and process control. To provide proper and reliable process control, online instrumentation must be able to measure the parameter in question from ten to thirty times more frequently that the *time constant* for the given parameter. The time constant for a parameter is defined as the time required for an operating parameter to achieve 63.2 percent of the difference between the initial and final conditions after a disturbance is introduced (Tchobanoglous et al, 2003). Time constants for various parameters can vary from less than one second (e.g., pressure) to more than a day [e.g., solids retention time (SRT)]. The trend is for more and more on-line process instrumentation process, especially where treated effluent is to be used for PR.

The purpose of most on-line wastewater process control instrumentation is to maintain one or several process parameters such as solids retention time (SRT) dissolved oxygen (DO), or clarifier sludge depth within a limited range of values. It should be noted, however, that the task of process control is considerably simpler when changes in external conditions, such as flowrate variation are minimized by means of flowrate equalization as discussed above. Development of improved operational strategies through the use of mathematical simulation has also been adopted by a number of wastewater agencies. Another trend today that will be even more important in the future will be the development of an ongoing program to test and evaluate new technologies.

4.4.9. Comparison of improved vs. conventional secondary effluent quality

Secondary effluent quality will, as can be expected, depend on types of treatment processes employed in a wastewater treatment plant. Representative effluent quality produced from different secondary wastewater treatment plants subject to normal flowrate variations are summarized in columns three through five in Table 4.3. The data in column six reflects the observed effluent characteristics where the flowrate variation was limited. As shown, although all of the treatment trains meet U.S. EPA secondary treatment requirement, the differences in final effluent quality is more pronounced on values related to nutrients, metals, pathogens, and measurements of organic and solids concentrations. It is important to note that the data presented in Table 4.3 are more qualitative than quantitative and should be used cautiously.

Table 4.3 Typical range of wastewater effluent quality produced from selective treatment processes

		Range of effluent quality from selected treatment processes				
Constituent/water quality parameter	**Unit**	**CAS**	**CAS with filtration**	**CAS with BNR**	**CAS with BNR and filtration**	**Membrane bioreactor**
Total suspended solids	mg/L	5-25	2-8	5-20	1-4	<1-5
Turbidity	NTU	2-15	1-5	1-5	1-5	<1-2
Biochemical oxygen demand	mg/L	5-25	<5-20	5-15	1-5	<1-5
Chemical oxygen demand	mg/L	4—80	30-70	20-40	20-30	<10-30
Total organic carbon	mg N/L	20-40	15-30	10-20	1-5	<0.5-5
Ammonia nitrogen	mg N/L	1-10	1-6	1-3	1-2	<1-5
Nitrate nitrogen	mg N/L	5-30	5-30	<2-8	1-8	<8
Nitrite nitrogen	mg N/L	0-trace	0-trace	0-trace	0.001-0.1	0-trace
Total nitrogen	mg N/L	15-35	15-35	3-8	2-5	<10
Total phosphorous	mg P/L	3-10	3-8	1-2	<1	0.3-5
Volatile organic compounds	μg/L	10-40	10-40	10-20	10-20	10-20
Iron and manganese	mg/L	1-15	1-1.4	1-1.5	1-1.5	Trace
Surfactants	mg/L	0.5-2	0.5-1.5	0.1-1	0.1-1	0.1-0.5
Total dissolved solids	mg/L	374-1121	374-1121	374-1121	374-1121	374-1121
Trace constituents	μg/L	5-40				
Total coliform	No./100 mL	10^4-10^5	10^3-10^5	10^4-10^5	10^4-10^5	<100
Protozoan oocysts	No./100 mL	10^1-10^2	0-10	0-10	0-10	0-10
Viruses	PFU/100 mL	10^1-10^4	10^1-10^3	10^1-10^3	10^1-10^3	10^0-10^3

Source: Tchobanoglous et al., 2015.

CAS = conventional activated sludge; BNR = biological nitrification removal

Part 5: The Path Forward and Implementation Challenges

The water shortage problem which Iran is now facing will only get worse if no action is taken. To alleviate the current water shortage problem, an integrated country-wide sustainable water resources management program must be developed. As part of the new integrated and sustainable approach, various forms of water reuse, including potable reuse, as discussed previously (see Parts 2 and 3), could play a vital and crucial role on helping water shortage problem in Iran. To implement potable water reuse in Iran, the water management authorities must take multiple important steps to make it a reality. Some important technological steps that can be taken have been discussed previously (see Parts 3 and 4). Additional considerations that can contribute to the successful implementation of potable water reuse program in Iran are discussed in this section.

5.1. The path forward for the potential use of potable water reuse in Iran

To expedite the path forward with the potential use of potable reuse program in Iran, serious consideration should be given to a sustainable wastewater management strategy involving the use of distributed wastewater management including: (1) utilization of decentralized (satellite) wastewater treatment facilities for water reuse, (2) use of satellite wastewater reclamation facilities in conjunction with advanced water treatment facilities, (3) addition of drinking water treatment plants adjacent to or near the satellite reclamation facilities, and (4) coupling desalination facilities with advanced water treatment facilities.

5.1.1. Utilization of decentralized wastewater treatment facilities for water reuse

In addition to the design modifications and operational changes to existing and proposed new WWTPs to enhance their performance, as discussed in Part 4, Iran should give serious consideration to the development of satellite wastewater reclamation plants, especially for large cities. Currently, in the major urban cities in Iran, wastewater is transported through the collection system to a centralized treatment plant located at the downstream end of the collection system near the point of dispersal to the environment. For example, in Tehran, the largest wastewater treatment plant is located in southern section of the city. Because centralized wastewater collection systems are generally arranged to route wastewater to these remote locations for treatment, water reuse for non-potable and potable use in urban areas is often inhibited by infrastructure costs for storing and transporting reclaimed water to the points of use (i.e., far from treatment plant) which render reuse uneconomic. An alternative to the conventional approach of transporting reclaimed water from a central treatment plant is the concept of decentralized (satellite) treatment facilities at upstream locations for both non-potable and potable reuse applications with solids processing at a regional facility. A schematic representation of a decentralized wastewater management system is illustrated in Figure 5.1.

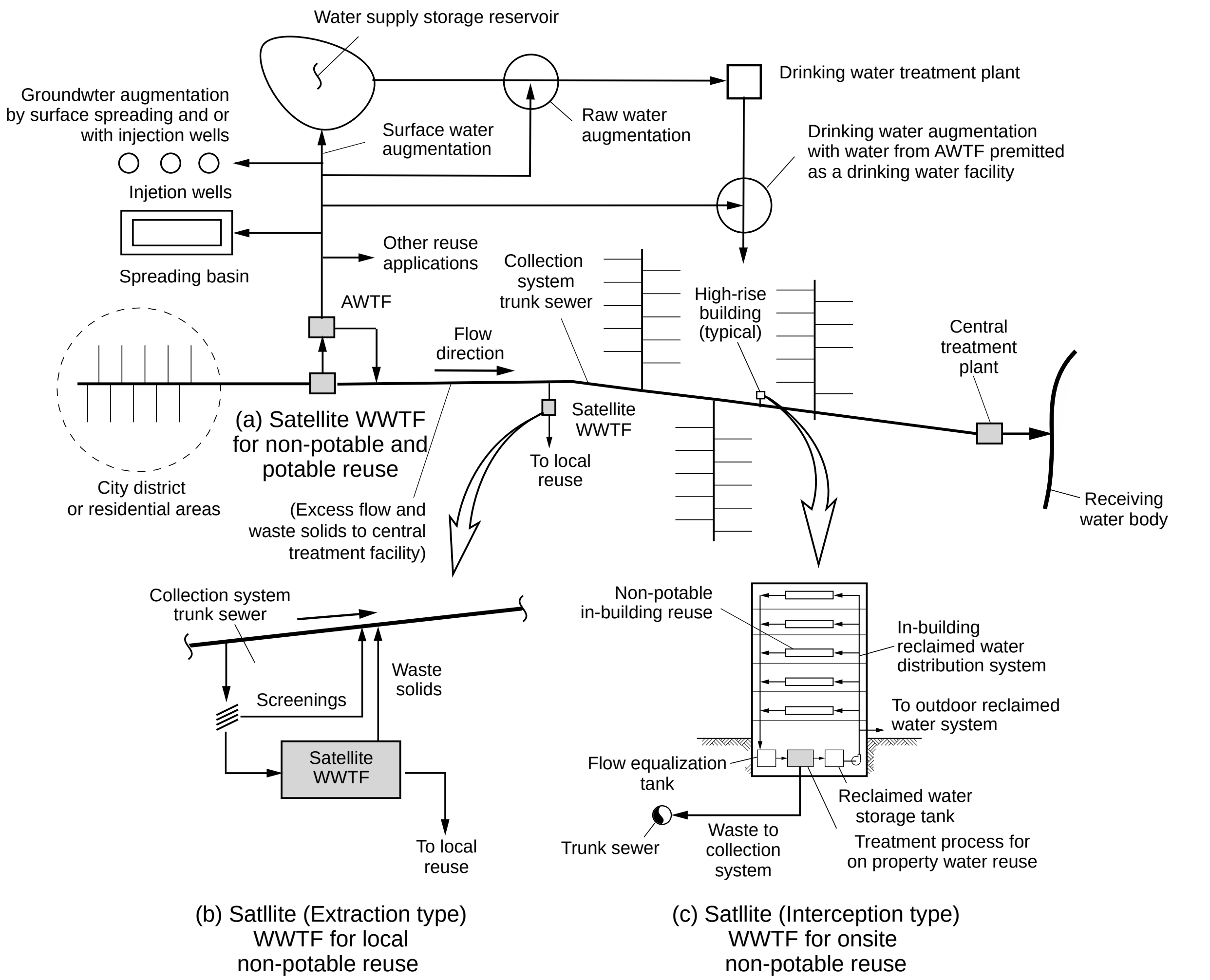

Figure. 5.1 Schematic view of an integrated decentralized wastewater management system employing satellite wastewater treatment facilities: (a) satellite WWTF for non-potable and potable reuse, (b) satellite (extraction type) WWTF for local non-potable reuse, and (c) satellite (interception type) WWTF for onsite non-potable reuses including toilet flushing, cooling water and landscape irrigation at building complexes (adapted from Tchobanoglous et al., 2014).

Three types of satellite facilities are shown in Figure 5.1. The first type is a conventional WWTF which is used to treat wastewater from one or more city districts or residential areas. Treated wastewater can be used for non-potable purposes and may also be used in conjunction with an advanced water treatment facility for indirect- and direct-potable reuse. In the second type of satellite facility (known as an extraction type), a portion of the flow from a wastewater collection main/trunk sewer is extracted, treated, and used locally. In the third type of satellite facility, (known as an interception type), wastewater is intercepted, treated and used locally for toilet flushing, cooling water, and landscape irrigation at building complexes, typically high-rise commercial and residential buildings. Any excess wastewater flow along with solids resulting from treatment are discharged to the wastewater collection system.

With a decentralized wastewater management strategy, treated wastewater can be used effectively at or near the point of waste generation. All of the operational changes and treatment design upgrade measures discussed previously in Part 4 can be incorporated into their design and operation. For example, the satellite reclamation plants would be operated at a constant flowrate without sludge processing facilities. Without the impacts of return flows, their operation will be much simpler and easier to monitor and control. The effluent of decentralized reclamation facilities can be used for a variety of water reuse applications including potable reuse by co-locating an advanced water treatment facility in the vicinity.

The use of upstream satellite wastewater reclamation plants is a well-established practice in California, including the City of Los Angeles, the County Sanitation Districts of Los Angeles County (CSDLAC), City of San Diego, and elsewhere in the United States. For example, the locations of satellite reclamation facilities with respect to the regional facilities in the City of Los Angeles and in the County Sanitation Districts of Los Angeles County is shown in Figure 5.2. In the case of CSDLAC, reclaimed water from a satellite plant is blended with imported river water and local stormwater runoff. The blended water has been used for groundwater replenishment since 1962.

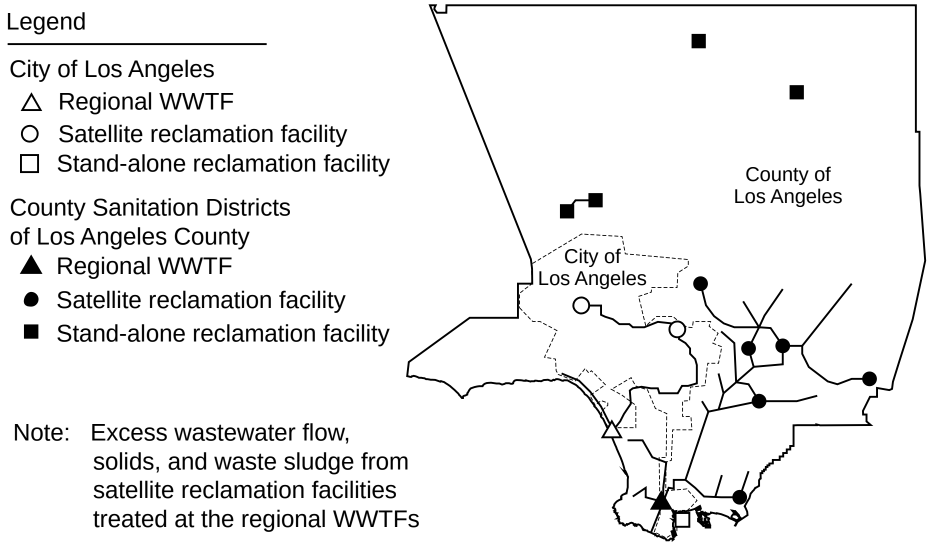

Figure 5.2. Location of satellite reclamation and regional facilities in the City of Los Angeles and in the County Sanitation Districts of Los Angeles County

Similarly, effluent from the Donald C. Tillman Water Reclamation Plant (DCTWRP) in the city of Los Angeles, put into operation in 1985, is used to irrigate a world famous 2.6 Hectare Japanese garden, to fill the 1.11 hectares lake located within the garden, and to maintain flow in the Los Angeles River (Coordinates: 34.182N 118.48W). In San Diego, the North City Reclamation Plant (NCRP), also a satellite plant was built to enhance local reuse of the treated effluent.

These examples of satellite treatment are presented to illustrate what can also be done in Iran as a first step in the development of a sustainable wastewater management program. The implementation of satellite reclamation facilities in Iran will require a new approach to the management and reuse of wastewater. Several methods of incorporating satellite treatment facilities into their new integrated sustainable water management plan are illustrated below.

5.1.2. Use of satellite wastewater reclamation facilities in conjunction with advanced water treatment facilities

Once satellite reclamation facilities are built, the next step would be to located advance water treatment facilities near or next to the water reclamation plants. The precedent for co-locating advance water treatment facilities is also well established. Perhaps the most famous example of co-locating wastewater management facilities is in Southern California where the Orange County Water District Advanced Water Treatment facility is located next to the Orange County Sanitation

District Water Reclamation facility (Coorinates: 33.692N 117.942W).

In the City of San Diego, the new advanced water treatment facility will be built next to the NCRP, as described above. Similarly, a new advanced water treatment facility is to be built on and adjacent to the DCTWRP, also described above. Here again, the same concept could be employed in urban cities of Iran such as Tehran. Because existing surface water reservoirs and water treatment plants in Tehran are located far away from potential locations where satellite treatment facilities could be located adjacently, transporting ATW to these upstream facilities will not be feasible economically. Hence, given these limitations, the most feasible reuse option for ATW produced from the future AWTFs in Iran is groundwater augmentation through direct subsurface injection. Using injection wells, the ATW can be used to help recover the groundwater aquifer which has been depleted by over extraction.

5.1.3. Addition of drinking water plants adjacent to or near the satellite reclamation facilities

In the more distant future, with new technology and increased experience, another possibility for potable water reuse would be to build a water treatment plant adjacent or nearby the upstream satellite treatment facilities described above. Given the high quality of the ATW, only reverse osmosis would be needed for drinking water treatment plant. Because of the high quality of the ATW operating expenses for the drinking water treatment plant would be significantly reduced as compared to treating raw water. With proper control, water from the drinking water facility would be introduced directly into the potable water distribution system. In addition, the water treatment plant could also be used to treat water extracted from the groundwater aquifer, if needed.

5.1.4. Coupling desalination plants with advanced water treatment facilities

Another option that should be considered, is to couple the seawater desalination plants with advanced wastewater treatment facilities. Advanced treated water would be combined with desalinated water and treated in a membrane type water treatment plant, permitted as a drinking water plant. The combined flow would be easy to treat, because both water sources are of high quality. Treating the combined flow would also enhance public health safety by provide an additional barrier. This scheme offers the advantage that drinking water could be used locally, thus avoiding the need for environmental buffers (e.g., groundwater or surface water) and long pipelines to deliver dilution water.

Yet another approach would be to produce high quality water for industrial uses by combining the water produced from seawater desalination and advanced wastewater treatment facilities. The brine from the advanced wastewater treatment facility could be blended with desalinated seawater. In Japan, as well as Singapore, high quality water from advanced wastewater treatment facilities is used in industrial applications. Use of water produced in this integrated approach increases the amount of water available for potable and other uses.

5.2. Implementation challenges for potable water reuse application in Iran

To move forward with the successful implementation of potable water reuse, Iran must overcome both technical and non-technical challenges. These topics are discussed briefly in this section.

5.2.1. Technical challenges

Aside from few older wastewater treatment plants in Isfahan and Tehran, the design and construction of majority of the centralized wastewater collection and treatment facilities in Iran is generally new and only recently implemented on the national basis. At present, no advanced water treatment facility has been designed or is operated in Iran for PR. Because of a lack of long-term experience, Iran may initially have to rely on foreign expertise for technical, construction, operation and monitoring aspects of potable water reuse projects. However, to move forward with future water resources management programs including potable reuse, Iran must also focus on developing within the country the required technical knowledge and expertise.

In general, from technical point of view, conventional wastewater treatment systems will need to be designed or modified to optimize their overall performance to enhance the reliability and performance of the AWTFs. Fortunately, the majority of the wastewater treatment plants designed and constructed in Iran are new and many more treatment plants are either under construction or under planning stage. So, it should not be very difficult to upgrade the existing wastewater treatment facilities or to incorporating some of the advanced treatment features to produce an effluent suitable for potable water reuse. Some of the technical issues with respect to upgrading the existing and for future design and operation of secondary treatment train systems as well as the advanced water treatment facilities in Iran were presented in Part 4. In addition, the methodologies presented in Part 4 could be considered when upgrading the existing and for future design and operation of satellite reclamation facilities in Iran.

5.2.2. Non-technical challenges

In addition to the technical challenges, cited above, Iran must also overcome multiple non-technical challenges including issues related to: public perception and acceptance, cultural and religious concerns, and institutional and regulatory requirements.

5.2.2.1. Public perception and acceptance challenges

Public perception and acceptance of reclaimed water for indirect and direct potable reuse is an important barrier that should be overcome before initiating potable water reuse program in Iran. Over the past decade, public knowledge about reuse has increased, particularly in arid regions of Australia and southwest of the U.S. as these communities see water reuse as part of their overall water portfolio. Iran can learn from these communities while educating the public and increasing their perception and acceptance toward the use of reclaimed water for potable reuse. Public perception with respect to water reuse has been studied with increasing interest in Australia since the mid-1990s (Russel and Lux, 2006), and with interest expanding globally since the early 2000s (e.g., Jeffery, 2002; Al-Kharouf et al., 2008; Marks et al., 2008; Ching, 2010; Domenech and Sauri, 2010; Haddad et al. 2010; Nellor and Millan, 2010). The importance of public perception to the successful establishment of water reuse projects has been found to be of "crucial importance" (Marks et al., 2008).

A recent study was conducted in Shiraz, Iran, to evaluate public perception concerning the acceptance of reclaimed wastewater for a variety of reuse applications (Baghapour et al., 2017). On average, it was found that 60 percent of the residents surveyed tended to have a positive view of water reuse for various applications. It was also found that the citizens of Shiraz are in favor of using reclaimed wastewater for applications with low skin contact including: non-potable urban applications (88%), car washing (86%), air conditioning (70%), toilet flush tank (81%), house cleaning (69%), crop irrigation [crops that are consumed raw (56%), and cooked food crops (64%)]. Nearly 75% of respondents opposed the use of reclaimed water for drinking and cooking. The main reason for their opposition was sanitary health concerns. With the availability advanced treatment technologies (see Part II) and with proper education and public outreach campaign, it will be possible to overcome the public objection for potable reuse applications, as has been done in numerous other communities (Fielding et al., 2018).

Along with the example studies cited above, two other valuable public outreach and public acceptance studies were performed by WateReuse Research Foundation (WRRF) in the United States. In the first study, funded by WRRF, it was found that while some staunch opponents are unlikely to change their position, a significant portion of community members may change their opinion to favor reuse water when provided clear information (WRRF, 2011). In this study, participants were provided information related to water reuse, including easy-to-understand technical details and graphics explaining the water purification process. Following this information sharing, most of those who had "minded a little," changed their opinion to "don't mind at all," though many had additional questions. Most who had indicated they "minded a lot" maintained that position. The principal findings from this research were: (1) that information presented to the public needs to be simple enough to understand yet technical enough to trust and (2) that public communications should be treated as a dialogue that avoids technical jargon and acronyms.

In the second study, funded by WRRF, it was found that the use of easy to understand vocabulary when communicating with the public often increased public acceptance of water reuse projects. The terms used to describe reclaimed water produced for augmentation of drinking water supply that survey respondents found the most reassuring all described the very high quality of the water and did not include the "re" prefix (reuse, reclaimed, etc.). At the other end of the spectrum, the terms found least reassuring are the terms most often used by the water industry (WRRF, 2012). In the WRRF study (WRRF, 2012), it was also found that most participants preferred that reclaimed water quality be described by the uses for which it is suitable, rather than a grading system, degree or type of treatment, or type of pollutants removed. It was also noted that the public is less concerned about the source of the drinking water supply than about monitoring and reliability of the safety and taste of their drinking water. Additionally, positive terminology leads to early acceptance of reuse water. The water purification plant described in the study appeared to strongly influence people's preference.

5.2.2.2. Cultural and religious challenges

In the WHO guidelines, it is recognized that in addition to technical issues, cultural and religious factors are important to the success of reclaimed water practice for non-potable and potable reuse. WHO reports that societal concerns related to use of untreated human excreta range from abhorrence to acceptance (WHO, 2006a). In Africa, the Americas, and Europe, excreta use is generally regarded with "disaffection," whereas in Asia its use is accepted and in keeping with Chinese and Japanese "traditions of frugality." In Islamic societies however, direct contact with excrement is abhorred however its use after treatment would be acceptable if the treatment were to remove impurities. Further, in Islamic countries it has been judged that wastewater can be used for irrigation provided that the impurities present in raw wastewater are removed (WHO, 2006b).

Several studies were performed to address the view of religion toward the use of recycled water for reuse applications. One study performed by Aitken et al. (2014) found that the respondents who identify as Islamic in England to be less accepting of recycled water for potable water. In another qualitative study conducted in South Africa with representatives of Muslim, Buddhist, Hindu and Christian showed that religion plays no important role in acceptance of recycled water (Wilson and Pfaff, 2008). The study found no evidence that followers of Islam automatically reject potable water recycling on religious grounds, and there were no religious objections from other religious groups or leaders. In the study conducted by Baghapour et al. (2017) in Shiraz, Iran, cited previously, it was found that only a small minority of people cited religious concerns in opposing recycled water. These findings align with the content of a report published by the United Nations University Press, concluding that wastewater reuse is permissible in Islam (Faruqui et al., 2001).

For the safe use of reclaimed water and greater acceptance by the public, a *Fatwa* [Rulings of a scholarly opinion on a matter of Islamic law issued by a recognized religious authority in Islam (About Islam, 2016)] may be required. However, it is not uncommon for scholars to come to different conclusions regarding the same issue. WHO (2006a) cites the 1978 Council of Leading Islamic Scholars of Saudi Arabia issuing a *Fatwa* concerning the use of wastewater in Islamic Societies which stated, "Impure wastewater can be considered as pure water and similar to the original pure water, if its treatment using advanced technical procedures is capable of removing its impurities with regard to taste, color and smell, as witnessed by honest, specialized and knowledgeable experts."

The following question was posed to the World Fatwa Management and Research Institute website in 2007: “From the Islamic point of view, is the reuse of treated wastewater permissible for irrigation of crops or park areas?” The response reads in part: “If water treatment restores the taste, color, and smell of unclean water to its original state, then it becomes pure and hence there is nothing wrong to use it for irrigation and other useful purposes” (INFAD, 2012).

One example water reuse project studied in Islamic society is the United States Agency for International Development’s (U.S. AID) Reuse in Industry, Agriculture and Landscaping (RIAL) in Jordan. RIAL project have engaged farmers in the successful use of treated wastewater in agricultural crop production. The projects have been successful because they have addressed not only technical and economic, but institutional and cultural issues as well (U.S. AID, 2008). The RIAL projects pioneered the first Water User Association (WUA) in Jordan for operation, maintenance and management of a wastewater-based irrigation system and the introduction of urban wastewater use for the first time in Jordan.

The RIAL projects have shown that reclaimed water can be used safely in agricultural irrigation. Social acceptance of these practices has no doubt been furthered by the understanding of the benefits derived from the reclaimed water and the acceptance of its use in this Islamic culture through the issuances of fatwas allowing water reuse in agriculture. The RIAL projects have demonstrated multiple benefits from well-managed water reuse projects including: (1) environmental improvement as wastewater was no longer discharged into streams and wadis, (2) increased farmer income, and (3) a resultant enhancement of the quality of life (Jordan Geography and Environment, 2016).

5.2.2.3. Institutional and regulatory challenges

Because multiple government agencies are now dealing with Iranian water management, conflicting interests must be addressed (Kayhanian and Tchobanoglous, 2016). The problem of conflicting jurisdictions can partially be resolved through adapting an integrated and sustainable water management plan. In addition, conflicting roles and responsibilities can be reformed and all quantitative and qualitative water management issues can be integrated under one existing agency or a new separate water agency.

At present, based on the knowledge of the authors, there is no national guidance on reclaimed water for potable reuse in Iran. Some water quality criteria have been established in 2010 for wastewater treatment and reuse in irrigation by the Ministry of Energy, Bureau of Engineering and Technical Criteria for Water and Wastewater (http://seso.moe.gov.ir). However, the existing water quality criteria must be updated with greater emphasis on public health protection using the reclaimed water for both non-potable and potable application.

Part 6: Closing Thoughts

As more large cities throughout the world experience water shortages, wastewater reuse in a variety of applications, including potable reuse, is both an attractive and feasible option. However, most large cities have also recognized the need to decentralize their wastewater management systems if they are to maximize the benefits of wastewater reuse. The trend to develop distributed wastewater management systems is also based on the fact that pumping advanced treated water to locations where it can be used effectively or to water storage reservoirs or water treatment facilities is, in most cases, prohibitively expensive, and especially so when the cost for the required infrastructure is considered. It is expected that this trend will continue in the future with the growth of new megacities in Iran and other mega cities in the regions.

To move forward with the successful implementation of water reuse including the application of potable reuse, aside from technical consideration on advanced treatment and regulatory requirements, Iran must devote especial attention to source control and improving the secondary effluent quality through treatment facility upgrades. To make the implementation of reuse more effective, Iran must devote further attention to non-technical issues such as public outreach and public education to change perception toward the acceptance of reclaimed water for potable reuse.

Because Iran is currently in the process of developing their wastewater management system, it can benefit from the distributed wastewater management experience in Southern California. In planning for distributed wastewater management, sufficient space should be available for the addition of an AWTF and ultimately a drinking water treatment plant, although the drinking water plant could be located elsewhere. What is important is that these concepts be given serious consideration in developing the long-term integrated country-wide sustainable water resources management program for Iran.

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Acronyms

ADF Average daily flow
ASR Aquifer storage and recovery
AWT Advanced water treatment
AWTF Advance water treatment facility
BAF Biological active filtration
BNR Biological nitrification removal
BOD Biological oxygen demand
C Cryptosporidium
CT Contact time
CAS Conventional activated sludge
CCPs Critical control points
CCR California Code of Regulation
CDPH California Department of Public Health
CEC Constituents of emerging concern
Cl Chlorination or chlorine disinfection
Cl2 Chlorine gas
COC Constituents of concern
CSDLAC County Sanitation District of Los Angeles County
CWA Clean water act
DAF dissolved air flotation
DBP Disinfection byproduct
DCTWRP Donald C. Tillman Water Reclamation Plant
DDW Division of drinking water (California) State (Water Resources Control Board)
DPR Direct potable reuse
DWTF Drinking water treatment facility
EC Electrical conductivity
ESB Engineered storage buffer
FRT Failure response time
FE Flow equalization
FS Filter screen
G Giardia
GAC Granular activated carbon
GW Groundwater
GWRS Groundwater Replenishment System
HAA5 Haloacetic acid (or halogenated acetic acid)
IPR Indirect potable reuse
IPRGR IPR for groundwater recharge
IX Ion exchange
LC Lime clarification
LAC Los Angeles county
MBR Membrane bioreactor
MCL Maximum contaminant level
MCLG Maximum contaminant level goal
MF Microfiltration
MRL Method reporting limit
NCRP North City Reclamation Plant
NDMA N-nitrosodimethylamine
NEB Natural environmental buffer
NF Nanofiltration
NPR Non-potable reuse
NRC National Research Council
NT Not tested
NWRI National Water Research Institute
O3 Ozone, ozination, or ozone disinfection
OCSD Orange County Sanitation District
OCWD Orange County Water District
PAC Powdered activated carbon
PDT Pressure decay testing
POTWs Publically owned treatment works
PR Potable reuse
PUB Public Utility Board (Singapore)
ReWA Reservoir water augmentation
RIAL Reuse in industry, agriculture and landscaping
RO Reverse osmosis
RTS Response time storage
RWA Raw water augmentation
RWC Recycled water contributions
SAT Soil aquifer treatment
SDWA Safe Drinking Water Act
SW Surface water
SWRCB State Water Resources Control Board
TCEP tris (2-Carboxylethyl) phosphine hydrochloride
TCEQ Texas Commission on Environmental Quality
TDWA Treated drinking water augmentation
TDWC Tolerable drinking water concentration
TDS Total dissolved solids
THMs Trihalomethanes
TOC Total organic carbon
TOrC Trace organic constituent (ore trace organic contaminant)
TSS Total suspended solid
UF Ultrafiltration
UV Ultraviolet
U.S.A. United States of America
U.S. AID United States Agency for International Development
U.S. EPA United States Environmental Protection Agency
V Virus
WHO World Health Organization
WRRF Water Reuse Research Foundation
WWT Wastewater treatment

Abbreviations for units of measure

bcm	Billion cubic meter
km	Kilometer
L/capita•d	Liter per capita per day
CT	Chlorine residual multiply by contact time
Da	Dalton or unified atomic mass unit is a standard unit that is used for indicating mass on an atomic or molecular scale (atomic mass) which is equivalent to 1.66 × 10-27 kg
kg	Kilogram
kWh	Kilowatt hour
kWh/m^3	Kilowatt hour per cubic meter
L/capita•d	Liter per capita per day
m	Meter
m^2	Square meter
m^3	Cubic meter
ha	Hectare
MCM	Million cubic meter
MFL	Million fibers per liter
mg/L	Milligram per liter or parts per million
µg/L	Microgram per liter billion
µm	Micrometer (1/1000 of meter)
ng/L	Nanograms per liter or parts per trilion
NTU	Nephelometric turbidity unit
pCi/L	Picocuries per liter (a measure of radioactivity in water)
PFU	Plaque forming unit
ppb	Part per billion
ppm	Parts per million
ppt	Parts per trillion
tonne	Metric tonne (1,000 kg)
u	unified atomic mass unit
WWTP	Wastewater treatment plant

Water scarcity is one of the main global challenges. This issue is even more critical in developing countries like Iran. Natural and anthropogenic forcing including climate change, disasters, fast development, and population growth add an extra pressure on water resources. We have one world with finite water resources. We need to reduce and reuse wastewater and help water cycle work more efficiently.

To overcome water-related challenges (quantity and quality of the water) towards sustainable water management, we need to remove the borders, fill the gaps between the public, scientists, policymakers, and also different countries and take quick, global, and sustainable actions all together.

This Technical Paper is prepared in response to a request from UNESCO Chair in Water and Environment Management for Sustainable Cities in Sharif University of Technology (Tehran, Iran). This paper can be of value in policy-making processes and in the development of water resources management plans.