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Treated Wastewater Reuse: A New Resource

Throughout the world, the availability of food and water is vital for the survival of humanity and to ensure an adequate standard of living. Increasing population, climate change and ongoing industrialization are putting pressure on existing water resources. Freshwater resources are not sufficient in all regions of the world. It is estimated that 50% of the world's population will live in water-stressed regions by 2030, underlining the importance of sound management and adequate water treatment. When water resources are limited, irrigation is severely penalized, as agriculture uses 70% of the total amount of water taken.

The water issue is inseparable from sustainable development, in that water must be able to meet the needs of present generations without jeopardizing the ability of future generations to satisfy their own. With the consequences of climate change, pressure on resources will continue to increase under the combined effects of population growth and policies implemented in respect of water-consuming activities. The water deficit will ipso facto lead to serious conflicts between the various users, which will inevitably require difficult arbitrations for public authorities. In many parts of the world, the 21st century is set to see a worsening of water shortages. According to the UNDP (United Nations Development Programme), an increase in global temperature of 3–4°C would cause a drought that would affect hundreds of millions of people. The IPCC (Intergovernmental Panel on Climate Change) confirms that the scale of impacts on water shortages would be dramatic.

For a color version of all figures in this chapter, see www.iste.co.uk/gaid/reuse1.zip.

Thus, water scarcity will affect not only irrigation for human food but also animal production (where water is essential both for drinking and feeding).

In order to improve agricultural production and minimize the depletion of natural water resources, a targeted low-cost water quality is needed. Wastewater reuse is a first solution.

1.1. Observations on the current situation[1]

The current situation is further exacerbated by several constraints: an imbalance between needs and available resources, a considerable increase in the needs for drinking, industrial and agricultural water, a geographical imbalance between needs and resources, pollution of groundwater and surface water and significantly reducing in some countries the volumes of water that can be used. The risk of a break in sustainable development may arise if the actual groundwater withdrawals exceed the limits for renewal of natural resources.

In Spain, April 2023 was one of the hottest and driest months recorded. Between the lack of fodder and soaring food prices, farmers had no choice but to slaughter their cattle.

In 2022, a prolonged drought affected many regions of France, Italy and Spain. The lack of precipitation combined with heat waves has led to dried out soils and a lack of water. The socioecological impacts of this drought were dramatic. The high water and thermal stress have significantly reduced yields of major crops such as corn, soybeans and sunflower, with reductions of about 15% in comparison to the last 5 years' average.

In Italy, about 50% of the population has been affected by water supply restrictions. High levels of salt intrusion from the Po Delta up to 40 km from the maritime coast have been recorded. The sharp drop in water levels in dams has severely impacted hydroelectric power and cooling systems of power plants.

In the south of France, fires associated with extreme drought conditions doubled compared to 2021 and were more than four times higher than during the 2012–2021 period. Sixty-six French departments were at the highest alert level in August, and

1 A few technical and scientific descriptions presented in this book were partly taken from the book *Drinking Water Treatment* (Gaid 2022), as the processes used in both applications were very similar.

93 departments were affected by all three alert levels. Similar impacts were observed in Spain and Portugal for agriculture, energy production and domestic water use.

The 2022 drought had significant societal impacts and the fear of future droughts is a major concern for populations (Breda and Badeau 2008; Baum et al. 2013; Faranda et al. 2023). According to the World Meteorological Organization, drought is one of the most damaging and deadly climate risks. In the coming years, drought-related rainfall deficits will become very problematic.

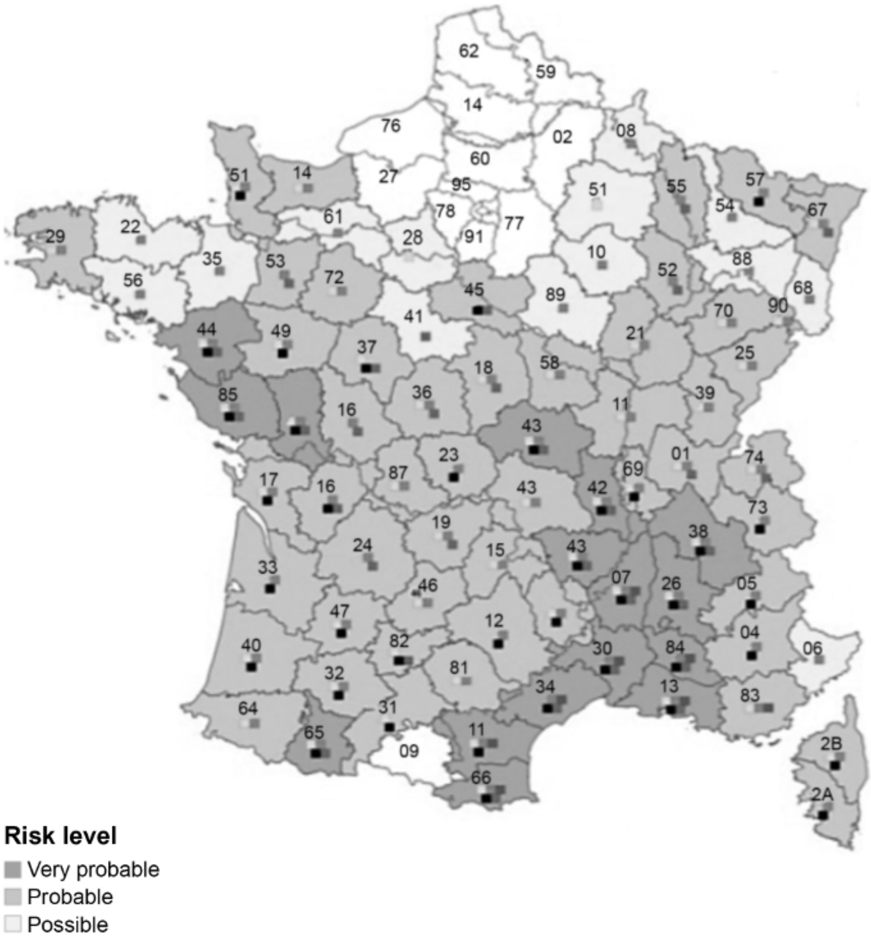

Figure 1.1. *(A) Maximum severity level limiting water use by department in force during the 2021 summer*

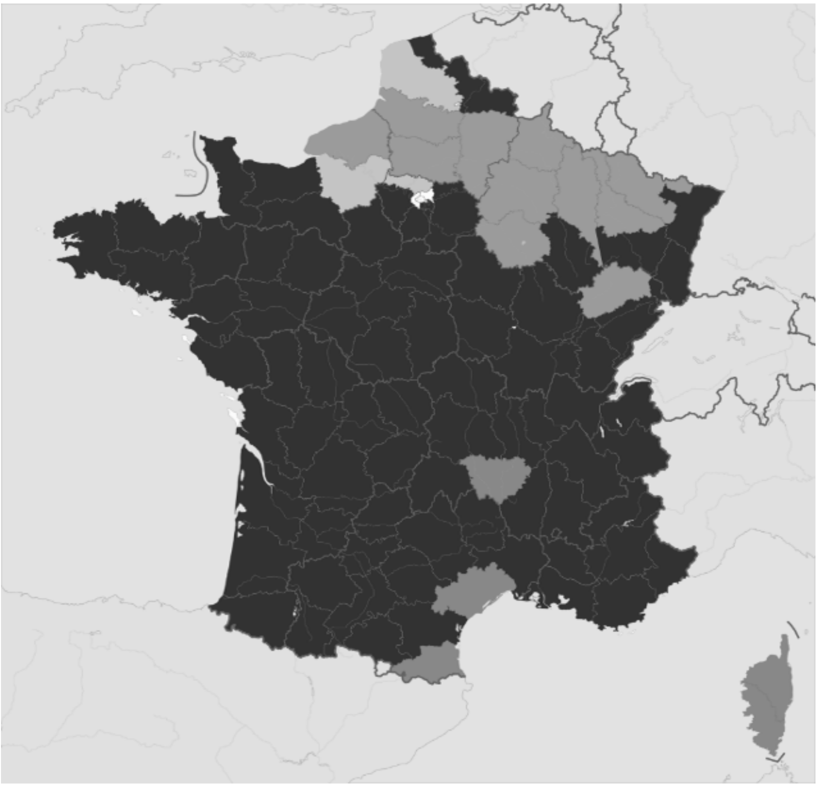

Figure 1.1. *(B) Maximum severity level limiting water use by department in force (continued) as of August 12, 2022 (source: Ministère de la Transition écologique et de la Cohésion des territoires)*

Figure 1.2. *Worsening of soil condition (France)*

Figure 1.3. *Lack of foods drives Spanish cattle farmers to massively kill cattle*

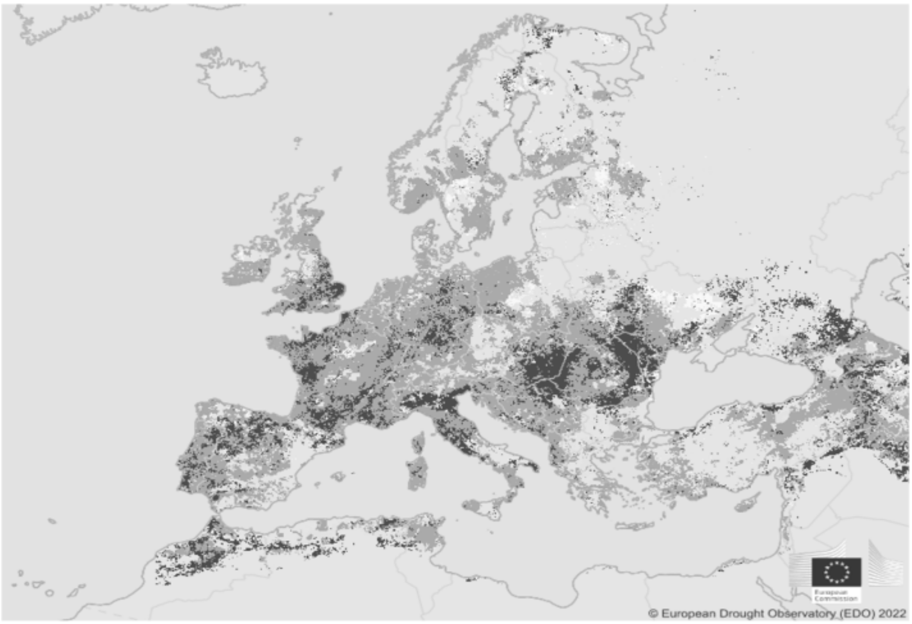

Figure 1.4. *Drought in Europe and North Africa (2022)*

The question of how much water resources will be available in the coming decades will be determined by climate change, even if water quality will depend on other factors such as infrastructure management, perimeter protection and pollution control. The expected and already observed summer drying in many countries has resulted in a number of impacts: tree health, natural resources, agriculture, water resources and hydroelectric power supply. Many regions of the world are concerned with the risk of increased frequency and intensity of heat waves and droughts.

1.2. Climate change

The role of climate change in the prolonged drought that affected Western Europe and the Mediterranean region in 2022 is now well established. Published in the journal *Environmental Research Letters*, a study conducted by a CNRS (National Centre for Scientific Research) team has established links between climate change and the occurrence of drought episodes, such as those encountered by France during the summer of 2022.

To demonstrate the responsibility of “anthropogenic climate change”, linked to human activity, these scientists used the method of “circulation analogues” to identify the atmospheric patterns of the 1836–2021 period and compare them with those of 2022. The process allows to highlight the responsibility of CO_2 emissions in the intensification and extension of high pressure zones behind the drought. “Results showed that the persistent anticyclonic anomaly on Western Europe during the drought was exacerbated by climate change due to humans, with larger and more extensive atmospheric pressure anomalies, as well as higher surface temperatures”, scientists report. It is concluded that these two factors exacerbated the drought, increasing the affected area and promoting soil drying by evapotranspiration (Ribes et al. 2022).

The climate data collected in the Mediterranean regions during the 20th century indicate an increased warming trend over the last 30 years. General circulation models converge to estimate a probable warming of the region in the range of 2–4°C during the 21st century. Climate modification would therefore be unavoidable and will have significant impacts, including increases in temperatures and precipitation, scarcity of water resources and increasing frequency of storms. Other impacts are loss of biodiversity, degradation of ecosystems, serious consequences for the whole range of socioeconomic activities due to the increased risk of famines, population movements and health impacts.

These changes will affect the retention of surface water and the useful capacity of dams, the renewal of groundwater levels. The latter point has already shown that drought combined with overexploitation of groundwater can lead to mineralization of unsaturated areas of deep aquifers. In coastal regions, the drop in hydrostatic pressure levels has already led to sea water entering the freshwater reserves of coastal aquifers. Climate change is having an impact on public health with potential for outbreaks of water-borne diseases. In North Africa, for example, this is due to insufficient water resources combined with the lack of treatment of some water points.

1.3. Solutions to reduce water stress

Some countries, such as the United States, Singapore and Namibia, have been pioneering for decades the implementation of the concept of treated wastewater reuse with alternatives for reusing drinking and non-drinking water. Wastewater treatment technologies currently provide solutions for adequate supply of reclaimed water. Therefore, the opportunities for water reuse exist, but the challenge lies largely in implementation. This is becoming urgent and necessary in regions where water stress is most pressing. Climate change will worsen the situation and drought periods will multiply. Total water demand will increase, especially for irrigation of field crops. As a result, water from natural resources such as groundwater and surface water will often be over-used.

The apprehension of climate change requires the implementation of strategies and controlled planning to satisfy water supplies. Only then will it be possible to meet the challenge of population growth and ensure safe drinking water for all. Alternative water sources must be produced to meet this challenge, as with drought, groundwater and surface water availability is already often insufficient and will be of great concern in many parts of the world, especially since the reduction of rain periods does not allow to fill dams, hill reservoirs and retention ponds.

Several solutions exist to reduce water stress with non-conventional waters:

– the desalination of non-conventional waters (sea water, oceans, estuaries, etc.);

– the use of fossil (non-renewable) groundwater;

– the reuse of wastewater.

Desalination is a good, very interesting, more expensive solution but primarily ensures the supply of coastal cities.

The use of fossil groundwater is another solution sometimes used, which has the major inconvenience of draining these reservoirs that are not renewable. Ground collapses were also observed when implementing this solution.

Figure 1.5. *Desalination and/or treated wastewater reuse*

Compared to desalination, even if drinking water applications, for example, are more reliable and reassuring, another alternative and sustainable resource is the reuse of treated wastewater. It stands as a new resource that can be directly available without passing through receiving environments. Water reuse is a cost-effective and energy-efficient option to increase water supply and mitigate the impact of climate variability and climate change. For all these reasons, treated wastewater reuse has emerged as the most promising, accessible and easy-to-implement solution. It is a voluntary and planned action, which aims at the production of additional quantities of water for different uses in order to fill water deficits.

1.3.1. *Direct and indirect reuse*

Direct reuse and indirect reuse have to be distinguished.

Direct reuse of treated wastewater is not to discharge wastewater into a river after treatment, but to immediately reinject it in a network for dedicated use (irrigation, watering green spaces or golf courses, cleaning roads, etc.). Direct reuse in France related to only 1% of wastewater, compared to 8% in Italy and 14% in Spain. This practice is highly developed in Israel, where 90% of wastewater is reused, without passing again in streams, most of them intermittent, meaning that these rivers only flow part of the year (BRGM 2010; Cerema 2020; Onema 2022).

Direct drinking water reuse is the supply of reused water that has undergone advanced complementary treatment and is sent directly to a drinking water treatment plant or distribution system, with or without intermediate storage. The potential barriers or disadvantages of this option are mainly related to public perception and acceptance rather than science or engineering.

Direct reuse is banned in France for drinking water and is not authorized for most food industries for health reasons.

Indirect reuse comes to draw water from a stream or its alluvial aquifer, while at a short distance upstream, a plant has discharged wastewater after treatment. The treated water has been diluted in the receiving medium. Indirect reuse is widespread in summer in all streams in France, where most irrigation is done by pumping rivers or alluvial aquifer. In other words, a significant part of the wastewater discharged in summer is already being reused in France or is used to maintain low water flow rates, except when stations discharge near the seafront or into the sea. Indirect reuse is permitted for all uses (BRGM 2010; Cerema 2020; Onema 2022).

This solution is widely practiced in many parts of the world and implies the availability of an environmental buffer zone (such as a lake, reservoir or aquifer). The water taken from this environment is then sent and injected upstream of the drinking water treatment plant.

Water reuse (also known as water recycling or water recovery) involves recovering water from various sources, and then treating and reusing it for beneficial purposes, such as agriculture and irrigation, drinking water supply, groundwater replenishment, industrial processes and environmental restoration. Water reuse can provide alternatives to existing water supplies and be used to improve water safety, durability and resilience.

Water reuse can be defined as planned or unplanned. Unplanned water reuse refers to situations in which a water source is essentially made up of previously used water. A common example of unplanned water reuse occurs when communities source water from streams, such as the Colorado and Mississippi rivers, which receive treated wastewater discharges from upstream communities.

Planned water reuse refers to water supply systems designed to advantageously reuse a recycled water supply source. Often, communities will seek to optimize their overall water use by reusing water as much as possible within the community, before the water is returned to the environment. Examples of planned reuse include agricultural and landscape irrigation, industrial process water, drinking water supply and groundwater supply management.

All water treatment facilities require a high level of reliability to ensure quality that meets standards and minimize, or even eliminate, any public health risk. This principle is particularly important in the case of RDP, where the risks of contaminants leaking after technical failures must be carefully controlled.

Three main water sources are the subject of these applications: water from domestic wastewater treatment plants, urban rainwater and industrial wastewater.

Direct reuse in coastal areas allows an additional valorization of wastewater whose discharge generates pollution (bathing water, risks for shellfish aquaculture, etc.).

The sprinkling of golf courses in France has sometimes reduced water withdrawals from communities. Similarly, in all contexts, direct reuse in town has potential (cleaning of roads and street furniture, green spaces or industry).

The reuse of treated wastewater is also considered when there is a need to protect a receiving environment, whether marine or underground, or when there is a water stress situation, which makes it necessary to conserve water resources.

The development of a territory, combined with urban, peri-urban or rural development projects, may involve recycling treated wastewater for the purpose of watering recreational areas, of agricultural or industrial use.

In most cases, the treated wastewater is discharged into natural watercourses where it undergoes further self-purification. They are then pumped to make drinking water for various industrial or agricultural uses. The receiving environment is known to promote the reduction of biodegradable pollutants in treated waters and, by dilution, reduces the impact of toxic elements. This last effect is highly limited, even unlikely, when the environment is water deficient.

The advantage of reuse is to create a shortcut for the accumulated mechanisms within the environment and to avail quickly of a water resource. In this case, in connection with the quality of the water obtained and the desired use, the availability of this new resource opens up immediate prospects.

Reuse of wastewater for direct consumption can raise public health and possibly religious concerns among consumers. Reuse as a means of freshwater supply is determined by economic and health factors involving water stress.

In North Africa, the Sahel and the Middle East, strong specificities govern water resources and their use, as these countries have mostly deserts that do not allow for renewable resources. Water stress in these countries creates complicated situations for agriculture and industry. Desalination plants have been installed where possible, but do not solve the problem in its entirety. The deficit remains high in desert areas.

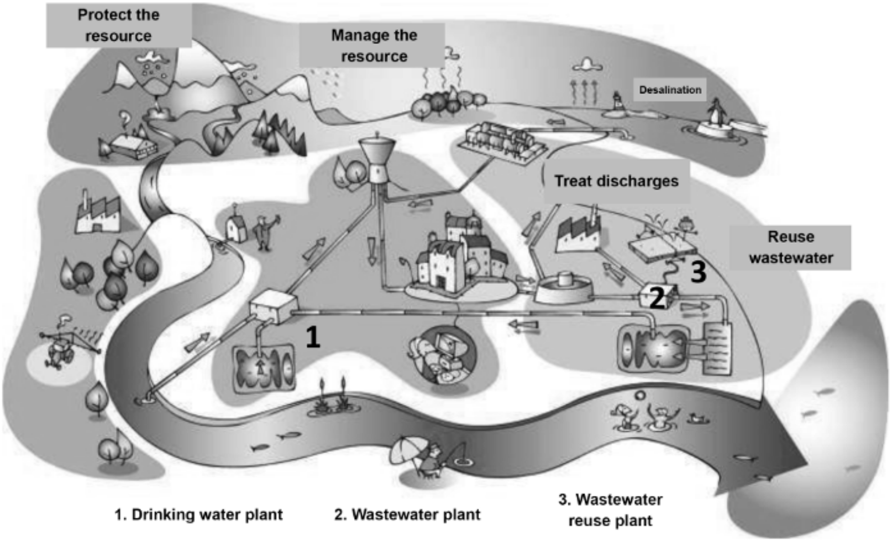

Figure 1.6. *Global water cycle after treated wastewater reuse*

In all the countries of the world where water stress has emerged, government strategies and policies have been focused on resource management and protection for the last 15 years, and also, in numerous cases on treated wastewater reuse.

Thus, in a world where cities are growing, and climate change threatens to exacerbate water scarcity in many parts of the world, treated wastewater reuse should be an integral part of water resource management, water supply and sanitation strategies.

To make wastewater an asset, an integrated approach that encompasses the entire water cycle – available water resources and supply options, water treatment and reuse – must be adopted.

As such, it is often recommended to:

– consider wastewater as a potential resource in the overall water balance;

– adopt an integrated framework to manage water supply, rainwater, wastewater, nonpoint sources, pollution and water reuse;

– integrate wastewater recovery and reuse into sustainable development and climate change as integrated water resource adaptation and management strategies;

– consider different reuse options from the outset in the design of wastewater treatment plants, as well as their operation, and define the corresponding standards;

– ensure that guidelines and policies encourage communities to identify cost-effective wastewater treatment solutions based on local capacity and reuse options, rather than imposing solutions or severely limiting them through overly strict regulations;

– involve all stakeholders from the outset in water reuse plans and provide multistakeholder platforms to facilitate dialogue, participatory technology development, innovation adoption and social learning;

– ensure financial stability and sustainability;

– link waste management to other economic sectors for faster cost recovery, risk reduction and sustainable implementation;

– develop public/private, public/public mixed solutions for investment, service delivery, operation and maintenance;

– take social equity into account when defining cost recovery mechanisms.

Climate change requires us to change our mentality and see wastewater as an alternative resource and an economic and environmental opportunity. Better wastewater management would actually help reduce water deficit, water scarcity and pollution of receiving environments.

1.4. The various purposes of reuse

Reusing a community's wastewater involves collecting, storing and using the wastewater for various purposes.

The various applications of treated wastewater reuse can be summarized as:

– urban environment (watering public parks, green spaces, sports fields, supply of water features and fountains, watering of private gardens, toilet flushing, washing of vehicles, street cleaning, fire circuits, etc.);

– industrial environment (cooling water, process water, etc.);

– agricultural (irrigation of various crops, market gardening, fruit trees, cereals, fodder, pastures, industrial crops and forests) and underground (groundwater recharge) environment;

– production of drinking water (groundwater recharge, direct production of drinking water);

– aquaculture;

– increase in drinking water;

– groundwater recharge;

– restoration of water bodies and wetlands;

– recreation areas.

Water reuse is already a widespread and accepted practice in many countries. Depending on its applications, the population may have negative opinions of it. Protests have been held in the states of a few countries against the use of recycled water for domestic purposes.

However, some countries have a long history of planned reuse and wastewater treatment plants producing water for various uses, including drinking water. In Namibia, South Africa and the United States, the strategies in place cover wastewater treatment – across a range of conventional and non-conventional systems – and national guidelines and regulations for reuse.

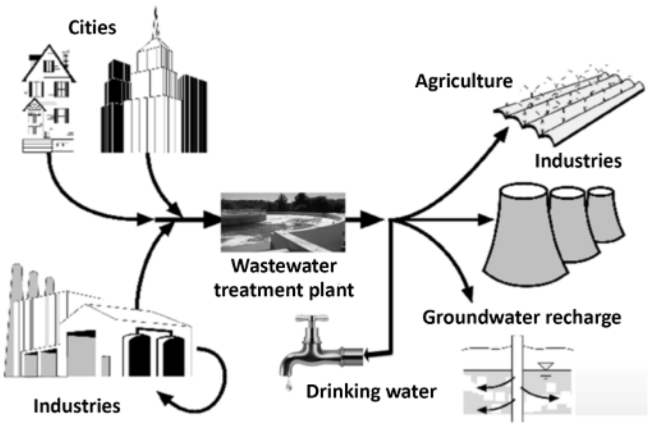

Figure 1.7. *Applications of treated wastewater reuse*

1.5. Adapting to the local context

In addition to treating wastewater as an asset, it is important that changes be made in a number of key areas for effective management of the global water cycle. For example:

– defining the most suitable and viable option for selected applications;

– taking into account local capabilities for operation, maintenance and downstream uses. Decentralized systems can better protect watersheds and water resources, and avoid long-distance wastewater transfers;

– managing water, wastewater, pollution control and water reuse in an integrated way within a comprehensive program;

– preferably, planning for the location of treatment to be within the vicinity of reuse sites;

– defining appropriate and cost-effective processing levels to match each reuse option;

– ensuring that water production meets water quality requirements for the specified use. Considering reuse from the outset in the design of wastewater treatment plants, as well as their operation, will provide the best results;

– changing to an approach where the treatment of raw wastewater and the complementary treatment for water reuse are combined in the same site. This helps to ensure the overall operation of the system, control the water quality and intervene very quickly in case of failure.

1.6. Policies and institutions to support reuse

The issue of treated wastewater reuse involves changes in our daily management of water consumption. For example, reinventing water efficiency, adopting innovative business models and mobilizing the water community.

In order to ensure public acceptance of water reuse, political will must be strengthened through constant information:

– The legislation may therefore have to define the access rights of users and the powers of the right holders. To ensure safe reuse, it is important to make access dependent on farmers' compliance with the reuse guidelines.

– Implementing economic incentives: incentives to reuse treated wastewater are useful where water users can choose between different sources of water.

– Bridging sectoral and administrative divides: effective wastewater management requires cooperation between agencies and sectors, such as health, municipal wastewater treatment, irrigation water distribution, etc.

– To get public understanding and acceptance, regulations on water reuse must include clear texts applying to drinking water, bathing water, irrigation water, drainage, etc.

– Public awareness, education and transparency: public awareness and education programs, including school programs, should be promoted.

– Transparency, information sharing and the involvement of water users in the decision-making process will also ensure greater acceptance of reuse projects. In the case of water reuse in agriculture, farmers must be educated on safe irrigation and post-irrigation practices, and consumers must be informed of the safety of agricultural products irrigated with well-managed recovered water. Quality data on water must be widely available and freely shared with water customers and the general public.

– Stakeholder participation should be encouraged as it is essential to success. Communities must be able to express their needs and suggestions in open multi-stakeholder platforms.

– Long-term strategies for progressive action and new local business models are also needed.

The reuse of wastewater is currently a socioeconomic issue for the development of drinking water and sanitation services. It has the advantage of providing an alternative resource to limit water deficits, better preserve natural resources and mitigate water shortages caused by climate change. Already, some countries, states and major cities (Australia, California, Cyprus, Spain, Florida, Israel, Jordan, Malta, Singapore, etc.) have ambitious targets of meeting 10–30% or even 60% of their water demand through the reuse of treated wastewater (Degrémont 2005).

This book presents wastewater characteristics, health risks, reuse regulations, various uses of reused water and the performance of conventional and membrane sectors: the ability to remove pollutants, the elimination of micro-organisms, the potential of membranes and reuse objectives.

Many examples are given from references in which the author has personally participated at the design and implementation level. The advantages and limitations of the processes are listed.

1.7. Glossary

There are many definitions of treated wastewater reuse in the regulations of many countries.

– *Direct drinking water reuse*: the reused water supply is further treated and then sent directly to a drinking water treatment plant or distribution system, with or without intermediate storage.

– *Direct recharge*: the treated wastewater exiting the wastewater treatment plant is directly injected into the groundwater. Direct recharge is usually accomplished via injection wells or equivalent.

– *Direct reuse*: it consists of not discharging the treated wastewater into a river, but reinjecting it immediately into a network for dedicated use (irrigation, watering of green spaces or golf courses, road cleaning, etc.).

– *Indirect reuse*: the water is taken from a stream or an alluvial aquifer, while at a short distance upstream a wastewater treatment plant has discharged wastewater after treatment. Treated water has been diluted in the receiving environment.

– *Planned reuse*: it includes situations in which treated wastewater is used directly or indirectly under quantitative and qualitative control.

– *Unplanned reuse*: it includes situations where supplies are from environments where wastewater has been discharged, and the quantity and quality of which is not controlled by the user.

– *Wastewater recycling*: often, this term is synonymous with reused water. However, in some countries, recycled water is more closely linked to internal recycling within an industry. The wastewater is collected, treated and then returned to the same industrial process circuit. In Canada, the term recycled water is defined as the return of treated wastewater to be reused for purposes that generate wastewater, for example, the treatment and recycling of all domestic wastewater for flushing toilets and other non-drinking uses.

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