Wastewater Technology Guide Development for Sustainable Water and Wastewater Management (Balkans, SEMED and Türkiye)

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Table of Contents

List of Tables

List of Figures

Abbreviations

°C	Degrees Celsius
ABH	Agence du Bassin Hydraulique
AC	Activated Carbon
ADMI	American Dye Manufacturing Institute Color Unit
ADt	Air Dry Tonne of Pulp Product
AOP	Advanced Oxidation Processes
AOX	Adsorbable Organically bound halogens
APEO	Alkylphenol Ethoxylates
API	Active Pharmaceutical Ingredient
BAT	Best Available Techniques
BCM	Billion Cubic Meters
BiH	Bosnia and Herzegovina
BMP	Best Management Practice
$BOD_{(5)}$	(5 Day) Biochemical Oxygen Demand
BREF	Best Available Techniques Reference Document
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CAPEX	Capital Expenditure
CIP	Cleaning in Place
COD	Chemical Oxygen Demand
CTMP	Chemithermomechanical Pulping
Da	Dalton
DAF	Dissolved Air Flotation
DDT	Dichlorodiphenyltrichloroethane (Pesticide)
DOC	Dissolved Organic Carbon
e.g.	for example
EBRD	European Bank for Reconstruction and Development
ED	Electrodialysis
EDTA	Ethylenediaminetetraacetic Acid
ENVITECC	Financing Advanced Environmental Technologies in the Mediterranean Sea Region for Water Systems and Clean Coasts
etc.	et cetera
EU	European Union
F&B	Food and Beverage
FAO	United Nations Food and Agriculture Organization
FO	Forward Osmosis
FOG	Fats, Oils, and Grease
g	Grams

GAC	Granular Activated Carbon
GDP	Gross Domestic Product
GEF	Global Environment Facility
GET	Green Economy Transition
GTS	Green Technology Selector
GW	Groundwood Pulp
HBGV	Health Based Guidance Value
hl	Hectoliter = 100 Liters
i.e.	that is
IR	Infrared
kg	Kilogram
km	Kilometer
KPI	Key Performance Indicator
kWh	Kilowatt Hour
log	Logarithm
m^3	Cubic meter
m^3/h	Cubic Meters per Hour
MBR	Membrane Bioreactor
MCM	Million Cubic Meters
MENA	Middle East and North Africa
mg/l	Milligram per liter = 1 ppm
Misc.	Miscellaneous
MWCO	Molecular Weight Cut-Off
N/A	Not Applicable
NACE	Nomenclature des Activités Économiques dans la Communauté Européenne
NF	Nanofiltration
nm	Nanometer
NOM	Natural Organic Matter
NPK	Nitrogen Phosphorus Potassium Fertilizers
OPEX	Operational Expenditure
ORP	Oxidation Reduction Potential
P&P	Pulp and Paper
PAC	Powdered Activated Carbon
PAH	Polycyclic Aromatic Hydrocarbons
PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
PFHxS	Perfluorohexane Sulfonate
PFOS	Perfluorooctane Sulfonic Acid
pH	A figure expressing the acidity or alkalinity of a solution

POP	Persistent Organic Pollutant
ppm	Parts per million
Pt-Co	Platinum-Cobalt Color Scale
RBD	River Basin District
RO	Reverse Osmosis
SDG	Sustainable Development Goal
SVOC	Semi-Volatile Organic Compounds
TDS	Total Dissolved Solids
TFC	Thin Film Composite
TKN	Total Kjeldahl Nitrogen
TMP	Thermomechanical Pulping
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TS	Total Solids
TSS	Total Suspended Solids
UEB	Unión Explosivos-Ensign Bickford company
UF	Ultrafiltration
UN	United Nations
US EPA	United States Environmental Protection Agency
US FDA	United States Drug and Food Administration
US$	United States Dollar
USA	United States of America
USAID	United States Agency for International Development
UV	Ultraviolet
VOC	Volatile Organic Compounds
VOX	Volatile Halogenated Compounds
yr.	Year
µg	Microgram
µm	Micrometer

Executive Summary

The European Bank for Reconstruction and Development (EBRD) is implementing the ENVITECC Programme funded by the Global Environment Facility (GEF), which focuses on the depollution of the Mediterranean Sea from the discharge of untreated wastewater and the removal of Persistent Organic Pollutants (POPs) in the region. The ENVITECC Programme covers Albania, Bosnia and Herzegovina, Egypt, Lebanon, Montenegro, Morocco, Tunisia, and Türkiye.

The objective of the ENVITECC Programme is to accelerate the adoption of technologies for reducing pollution, improving wastewater management and treatment, and improving chemicals and waste management across the Mediterranean region.

The ENVITECC Programme is aligned with EBRD's Green Economy Transition (GET) approach by supporting investments that promote the sustainable use of resources and protection of natural assets by emphasizing innovation and the introduction of new technologies, equipment, and practices into the target markets.

Under the ENVITECC Programme, this guide has been developed to identify best available techniques and practices for sound and sustainable wastewater management through off-the-shelf available technology options for reuse of treated wastewater and stormwater and reduction of wastewater generation through avoidance and minimization of water consumption focusing on priority use areas in industrial sectors in the ENVITECC countries.

Country specific water and wastewater profiles for each ENVITECC country detailing water availability at national level, water consumption at sectoral level and wastewater management practices at sectoral level have been outlined. The target sectors include food & beverage, pulp & paper, chemicals, textile, primary metals, power, and mining.

A general overview of the target industrial sectors has been provided including typical water consumption figures, typical wastewater characteristics, and off-the-shelf wastewater treatment techniques and practices commonly applied at each sector.

Within the scope of this Wastewater Technology Guide, off-the-shelf available advanced wastewater treatment techniques enabling the implementation of wastewater reuse initiatives have been identified with the aim of onboarding to the EBRD's Green Technology Selector (GTS) Platform. GTS is a global online platform launched by the EBRD in 2018. It connects technology providers of the best green technologies with forward-thinking businesses and homeowners. The platform is designed to facilitate the selection and implementation of sustainable technologies across various sectors.

In the context of the ENVITECC, the GTS platform can play a crucial role in disseminating the findings of the Wastewater Technology Guide. The identified technologies and practices for sustainable wastewater management can be made available on the GTS platform, providing businesses in the ENVITECC countries with easy access to this information. This will support goal of the ENVITECC to accelerate the adoption of technologies for reducing pollution, improving wastewater management and treatment, and improving chemicals and waste management across the Mediterranean region.

1. Country Specific Background Information

This section provides a snapshot of country specific water and wastewater profile for each ENVITECC country based on most recent data structured as follows:

- General geographic, demographic and climate information
- Data on water availability at country level including water stress and scarcity indicators
- Data on water consumption at sectoral level (domestic, tourism, agricultural, and industrial) with benchmarks against Good International Practices. The covered industrial sectors are the food & beverage, chemicals, primary metals, textiles, mining, power, and pulp & paper sectors
- Data on wastewater management practices at sectoral level with benchmarks against Best International Practices. The covered categories are reuse of treated wastewater and reuse of stormwater

This section was compiled through comprehensive desk-based research with references obtained from credible sources. The order of precedence for data retrieval was as follows:

- Governmental sources (e.g., ministries, agencies)
- International organizations studies, reports, and databanks (e.g., EBRD, USAID, UN, WorldBank, FAO Aquastat, Eurostat, etc.)
- Books and peer-reviewed journals
- Open-source web articles

Several datasets were difficult to obtain, mainly on water consumption per industrial subsector and wastewater management practices. Engicon has endeavored to fill in the gaps as much as possible; however, in cases where no solid assumptions were able to be made, the data was marked as unavailable.

Throughout this section, several specific terms were used and are defined as follows:

- **SDG 6.4.2 Indicator, Level of Water Stress:** The indicator monitors how much freshwater is being withdrawn by all economic activities compared to the total renewable freshwater resources available. The indicator is computed as the total freshwater withdrawn divided by the difference between the total renewable freshwater resources and the environmental flow requirements, multiplied by 100 [1]. Other water stress indicators are available such as the total renewable water resources per capita per year benchmarked against the Falkenmark water stress index (included in this report), the World Resource Institute Aqueduct [2], and the World Wide Fund for Nature Water Risk Filter [3].

- **SDG 6.1.1 Indicator, Proportion of Population using Safely Managed Drinking Water Services:** Safely managed services indicate drinking water from an improved water source which is located on premises, available when needed and free from fecal and priority chemical contamination [4].

- **SDG 6.1.1 Indicator, Proportion of Population using at Least Basic Drinking Water Services:** Basic services indicate drinking water from an improved source provided collection time is not more than 30 minutes for a roundtrip including queuing. The term at least basic refers to populations with either basic or safely managed services [4].

- **SDG 6.2.1 Indicator, Proportion of Population using Safely Managed Sanitation Services:** Safely managed services indicate the use of improved facilities which are not shared with other households and where excreta are safely disposed in situ or transported and treated off-site [5].
- **Water Use per Capita per Day:** According to an article published by the European Commission in 2018, average usage of tap water by EU states is 120 liters per capita per day with the highest being 243 liters in Italy and the lowest being 50 liters in Malta. The UK stands at 150 liters per capita per day. For the estimation of the water consumption for the tourism sector, the value of 150 liters per capita per day was adopted [6].

1.1. Albania

Albania is located at the western side of the Balkan Peninsula in southeastern Europe, bordering Montenegro to the northwest, Kosovo to the northeast, North Macedonia to the east and Greece to the south. The majority of the country's western border is a long coastline along the Adriatic and Ionian Seas (Figure 1).

Figure 1: Map of Albania [7].

Worldwide, Albania is currently ranked 144th with regards to total surface area and 136th with regards to population [8]. Table 1 below summarizes selected geographic and demographic data for Albania.

Table 1: Albania's Geographic and Demographic Data.

Characteristic	Value	Reference
Total Surface Area (km^2)	28,748	[8]
Coastline (km)	362	[8]
Population (inhabitants) (2022)	3,095,344	[8]
Population Density (inhabitants/km^2) (2022)	108	Author's Calculation
Total GDP (current US$ Billion) (2021)	18.3	[9]

Albania's topography is predominantly hilly and mountainous with the highlands above an altitude of 300 meters representing 75% of its territory. The remainder consists of costal and alluvial lowlands. Albania's climate generally varies with its topography. The coastal plains experience hot and dry summers and wet and mild winters while the mountains experience colder summers and severe winters accompanied by heavy snow [10]. Climate projections indicate that Albania could possibly face more extreme weather by 2050 with increased floods, droughts, heatwaves and a likely decrease in summer rainfall. As a result, Albania's water resources are particularly vulnerable to the effects of climate change due to a likely alteration in river flows, decrease in water percolation to groundwater reserves, shift in runoff patterns, and damage to water infrastructure caused by flooding [11].

1.1.1. Water Availability

Albania is abundant in conventional water resources. Surface water resources include rivers, lakes, and lagoons. Albania's seven main rivers are the Drini, Mati, Ishmi, Erzeni, Shkumbini, Semani and Vjosa Rivers. These rivers flow from east to west and discharge 95% of their flow into the Adriatic Sea while the remainder is discharged into the Ionian Sea. About 250 natural lakes exist in Albania with the largest three Lake Ohrid, Lake Prespa and Lake Shkoder being transboundary lakes. Along the coast, Albania has several lagoons with the largest two being Karavasta and Narta Lagoons [12].

Groundwater resources in Albania are found in various geological formations dating from Paleozoic to Quaternary era. Albania's groundwater resources are classified according to the river basin and include the Drini-Buna, Mati, Erzeni-Ishmi, Shkumbini, Semani, and Vjosa Basins. Albania's groundwater resources are vital to the country as they are the main source of drinking water. However, not much is yet known about the groundwater's true availability and extraction capacity due to the lack of proper studies and monitoring programs [13].

Non-conventional water resources include treated wastewater. By 2016, Albania had built 8 urban wastewater treatment plants; however, lack of financial capacities and limited technical capacities rendered three of them idle. More urban wastewater treatment plants are under construction such as in Tirana [12]. Nevertheless, the overall status of current and future plans in wastewater treatment remains unclear due to the lack of publicly available information. With regards to desalinated seawater, no information was found concerning its practice in Albania, which may be due to the country's reliance on the abundant conventional water resources.

According to the United Nations SDG 6.4.2 indicator, level of water stress, Albania falls within the 0 and 25th percentile category, and hence is at *No Stress* level [1]. Moreover, the total renewable water resources per capita per year is way above the 1700 m^3/capita/yr. threshold for water stress as defined by the Falkenmark water stress index [14].

Table 2 below lists Albania's available water resources including water stress and scarcity indicators. As can be seen from the table, Albania has abundant conventional water resources and is currently classified under no water stress conditions. Nevertheless, several studies have raised concerns with regards to Albania's future water stability due to the lack of proper resource management, lack of monitoring programs, climate change and the deteriorating water quality [11], [12], [15], [16].

Table 2: Albania's Water Availability Profile and Water Stress Indicators.

Characteristic	Value	Reference
Conventional Water Resources		
Surface Water (MCM/yr.) (2018)	39,000	[12]
Groundwater (MCM/yr.) (2018)	9,000	[12]
Non-Conventional Water Resources		
Desalinated Seawater (MCM/yr.)	No information found/publicly available	
Water Stress and Scarcity Indicators		
Total Renewable Water Resources per Capita (m^3/capita/yr.) (2019)	10,483	[17]
Level of Water Stress: Freshwater Withdrawal as a Proportion of Available Freshwater Resources (%) (2019)	6.8	[1]

1.1.2. Water Consumption

The proper evaluation of water use in Albania is challenging due to the lack of adequate monitoring programs. In 2020, the total water abstraction across all sectors from surface water and groundwater resources accounted to 704.2 MCM and 81.3 MCM, respectively. 76.2% of the abstracted surface water was utilized by the agricultural sector, while 82.1% of the abstracted groundwater was utilized by the domestic sector [18]. In 2020, the United Nations reported under SDG 6.1.1 indicator that the proportion of Albania’s population using safely managed drinking water services stands at 70.7%, which lags behind the average of 96.0% for Europe and Northern America [4].

In 2020, Albania’s tourism sector contributed 8.2% to the total GDP [19]. No data was found concerning any trends in water usage for the tourism sector. However, Albania had 5,689,000 foreign arrivals in 2021 [20]. Assuming the typical 150 liters per person per day and an estimated visit of 7 days, water usage can be estimated at 6.0 MCM/yr.

Water consumption among the different industrial sectors can vary significantly and is highly dependent on the type of sector, nature of its operation and the type of finished products. Albania’s major industrial sectors include food & beverage, footwear, apparel and clothing, lumber, oil, cement, chemicals, mining, basic metals, and hydropower [8].

Table 3 below lists Albania’s water consumption per sectors. The largest water consumer is the agricultural sector followed by the domestic and industrial sectors.

Table 3: Albania’s Water Consumption Profile.

Sector	Value (MCM/yr.)	Reference
Domestic (2020)	225.3	[18]
Tourism (2021)	6.0	Author’s Estimation
Agricultural (2020)	544.6	[18]
Industrial (2020)	15.6	[18]

Sector	Value (MCM/yr.)	Reference
Food & Beverage (2020)	2.3	[21]
Chemical	No information found/publicly available	
Primary Metals (2020)	0.8	[21]
Textile	No information found/publicly available	
Mining (2020)	10.9	[18]
Power	No information found/publicly available	
Pulp & Paper	No information found/publicly available	
Other Industrial Sectors (2020)	1.6	[21]

1.1.3. Wastewater Management Practices

In 2020, the United Nations reported under SDG 6.2.1 indicator that the proportion of Albania's population using safely managed sanitation services stands at 47.7%, which lags behind the average of 78.0% for Europe and Northern America [5]. As previously mentioned, by 2016 Albania had built 8 urban wastewater treatment plants with several others planned or under construction [12]. In 2020, Albania was only able to treat 10.5% of the total generated wastewater from urban sources [22].

No data was found on wastewater management practices in Albania, nor any significant data on the quality and quantity of the discharged wastewater. Both treated and untreated wastewater generated from various sources is commonly discharged into respective waterbodies. The current practice raises serious concerns with regards to surface water and groundwater pollution [12]. Additionally, no data was found regarding any reuse practices of the treated wastewater.

With regards to stormwater, no data was found regarding its capture and reuse. Albania's mean annual precipitation is estimated at 1,485 mm/yr.; ranked 61st out of the 182 reported countries worldwide [23]. Several recent articles have illustrated use-cases for the capture and reuse of stormwater in household and commercial buildings [24], [25], [26]. According to [24], the authors estimated that 30% of the yearly water demand for hygienic sanitary services, washing clothes, and irrigation at a kindergarten in Tirana can be met by the installation of a simple stormwater collection system.

Table 4 below lists Albania's wastewater management practices. Unfortunately, no data was found with regards to any reuse practices for treated wastewater nor stormwater.

Table 4: Albania's Wastewater Management Practices Profile.

Characteristic	Value (MCM/yr.)	Reference
Wastewater Generation & Treatment		
Urban Wastewater (2020)	68.0	[22]
Total Wastewater Discharged After Treatment (2020)	7.1	[22]
Total Wastewater Discharged Without Treatment (2020)	60.9	[22]

Characteristic	Value (MCM/yr.)	Reference
Reuse of Treated Wastewater		
Domestic	No information found/publicly available	
Agricultural	No information found/publicly available	
Industrial	No information found/publicly available	
Reuse of Stormwater		
Domestic	No information found/publicly available	
Agricultural	No information found/publicly available	
Industrial	No information found/publicly available	

1.2. Bosnia and Herzegovina

Bosnia and Herzegovina (BiH) is located at the western side of the Balkan Peninsula in southeastern Europe, bordering Croatia to the north, west and southwest, Serbia to the east, and Montenegro to the southeast. To the southwest, BiH has a small coastline with access to the Adriatic Sea (Figure 2).

Figure 2: Map of Bosnia and Herzegovina [27].

Worldwide, BiH is currently ranked 128th with regards to total surface area and 130th with regards to population [28]. Table 5 below summarizes selected geographic and demographic data for BiH.

Table 5: Bosnia and Herzegovina's Geographic and Demographic Data.

Characteristic	Value	Reference
Total Surface Area (km^2)	51,197	[28]
Coastline (km)	20	[28]
Population (inhabitants) (2022)	3,816,459	[28]
Population Density (inhabitants/km^2) (2022)	75	Author's Calculation
Total GDP (current US$ Billion) (2021)	23.4	[9]

BiH’s topography is mountainous with the highlands above an altitude of 500 meters representing 42% of its territory. The remainder consists of 24% hills, 5% lowlands, and 29% karst [29], [30]. BiH’s climate generally varies with its topography. The mountains experience alpine climate while the plains and hills at the country's center experience moderate continental climate. Along the lowlands and Adriatic coast, the climate is generally Mediterranean. Climate projections indicate that BiH could possibly face more extreme weather in the future with intense precipitation, floods, droughts, and a likely decrease in summer rainfall. As a result, BiH’s water resources are particularly vulnerable to the effects of climate change due to a likely decrease in river flows, decrease in potable water quality, increase in flash floods affecting water services infrastructure, and an increase in water loss from evaporation and transpiration [31].

1.2.1. Water Availability

BiH is abundant in conventional water resources. However, the country has uneven distribution of water resources with noticeable seasonal variations [29]. BiH has two main River Basin Districts (RBD’s): the larger Sava RBD flows into the Black Sea while the smaller Adriatic Sea RBD drains into the Adriatic Sea. Surface water resources include rivers and lakes. BiH’s major rivers are the Una, Sana, Vrbas, Bosna, Drina, Neretva, and Sava Rivers. On the other hand, Lakes are characterized according to their type and include river lakes (found in the Pliva, Una and Trebizat Rivers), mountain lakes (found in the Dinarides), seasonal lakes (found in karst fields of the Adriatic Sea RBD), and intermittent lakes [29].

BiH’s groundwater resources are generally characterized according to their geographical location and special characteristics e.g., porosity. In the Sava RBD, 8 large aquifers of intergranular porosity and 21 of karst-fracture porosity are identified while for the Adriatic Sea RBD, 1 large aquifer of intergranular porosity and 13 of karst-fracture porosity are identified [32].

Non-conventional water resources include treated wastewater. By 2018, BiH had 17 urban wastewater treatment plants in operation [29]. With regards to desalinated seawater, no information was found concerning its practice in BiH, which may be due to the country’s reliance on the abundant conventional water resources and its limited access to the sea.

According to the United Nations SDG 6.4.2 indicator, level of water stress, BiH falls within the 0 and 25th percentile category, and hence is at *No Stress* level [1]. Moreover, the total renewable water resources per capita per year is way above the 1700 m^3/capita/yr. threshold for water stress as defined by the Falkenmark water stress index [14].

Table 6 below lists BiH’s available water resources including water stress and scarcity indicators. As can be seen from the table, BiH has abundant conventional water resources and is currently classified under no water stress conditions.

Table 6: Bosnia and Herzegovina's Water Availability Profile and Water Stress Indicators.

Characteristic	Value	Reference
Conventional Water Resources		
Surface Water (MCM/yr.) (2019)	36,340	[33]
Groundwater (MCM/yr.) (2019)	11,570	[33]
Non-Conventional Water Resources		
Desalinated Seawater (MCM/yr.)	No information found/publicly available	
Water Stress and Scarcity Indicators		
Total Renewable Water Resources per Capita (m^3/capita/yr.) (2019)	11,360	[17]
Level of Water Stress: Freshwater Withdrawal as a Proportion of Available Freshwater Resources (%) (2019)	2.0	[1]

1.2.2. Water Consumption

In 2019, the total water abstraction by the entities managing public water supply from surface water and groundwater resources accounted to 55.1 MCM and 250.5 MCM, respectively, while 6.3 MCM was acquired from other water supply systems [34]. 47.4% of the total water was reported as delivered to end-users, while the remaining 52.6% was reported as losses in the water mains. The percentage of delivered water to the domestic, industrial, and agricultural sectors was reported as 72.2%, 8.5% and 1.0%, respectively, with the remainder to other applications. In 2020, the United Nations reported under SDG 6.1.1 indicator that the proportion of BiH's population using safely managed drinking water services stands at 88.9%, which slightly lags behind the average of 96.0% for Europe and Northern America [4].

In 2020, BiH's tourism sector contributed 2.2% to the total GDP [19]. No data was found concerning any trends in water usage for the tourism sector. However, BiH had 502,000 foreign arrivals in 2021 [20]. Assuming the typical 150 liters per person per day and an estimated visit of 7 days, water usage can be estimated at 0.5 MCM/yr.

Water consumption among the different industrial sectors can vary significantly and is highly dependent on the type of sector, nature of its operation and the type of finished products. BiH's major industrial sectors include steel, coal, iron ore, lead, zinc, manganese, bauxite, aluminum, motor vehicle assembly, textiles, tobacco products, wooden furniture, ammunition, domestic appliances, and oil refining [28].

Table 7 below lists BiH's water consumption per sectors. The largest water consumer from the public water supply is the domestic sector followed by the industrial and agricultural sectors. It should be noted that the values reported for the domestic and agricultural sectors only account for the water used from the public water supply and do not include possible direct use from surface water and groundwater resources; no information was found with that regard. Moreover, the value reported for the "industrial from overall sources" could include the portion reported under the "industrial from public water supply" i.e., possible double counting.

Table 7: Bosnia and Herzegovina's Water Consumption Profile.

Sector	Value (MCM/yr.)	Reference
Tourism (2021)	0.5	Author's Estimation
Domestic - from Public Water Supply (2019)	106.9	[34]
Agricultural - from Public Water Supply (2019)	1.4	[34]
Industrial - from Public Water Supply (2019)	12.6	[34]
Industrial - from Overall Sources (2019)	64.0	[35]
Food & Beverage (2019)	4.9	[35]
Chemical (2019)	14.4	[35]
Primary Metals (2019)	23.8	[35]
Textile (2019)	0.3	[35]
Mining (2019)	9.2	[35]
Power	No information found/publicly available	
Pulp & Paper (2019)	9.8	[35]
Other Industrial Sectors (2019)	1.5	[35]

1.2.3. Wastewater Management Practices

In 2018, the United Nations reported under SDG 6.2.1 indicator that the proportion of BiH's population using safely managed sanitation services stands at 40.3%, which significantly lags behind the average of 78.0% for Europe and Northern America [5]. As previously mentioned, by 2018 BiH had 17 urban wastewater treatment plants in operation [29] and in 2021 was able to treat 36.9% of the wastewater inflow into the public sewerage system [36]. Moreover, BiH was also able to treat 66.0% of industrial wastewater inflow to non-public treatment plants [37].

For BiH, no data was found regarding any reuse practices of treated wastewater. However, for the reported wastewater treated by public treatment plants, the percentage of wastewater treated by secondary and tertiary treatment was reported as 91.9% and 5.8%, respectively [36]. Similarly, for treated industrial wastewater by non-public treatment plants, the percentage of wastewater treated by secondary or tertiary treatment was reported as 5.9% and 21.1%, respectively [37]. As per the definitions, secondary treatment entails reduction in TSS and BOD_5 by 70.0% to 90.0% and COD by 75.0%, while tertiary treatment entails the reduction in the concentration of nutrients not removed by secondary treatment by as much as 80.0%. Generally, wastewater that has undergone treatment up to these standards and fulfills the reuse criteria stipulated by the country's national laws has high potential for reuse in various purposes such as irrigation and in other applicable sectors.

With regards to stormwater, no data was found regarding its capture and reuse nor any use-case articles. BiH's mean annual precipitation is estimated at 1,028 mm/yr.; ranked 93rd out of the 182 reported countries worldwide [23]. Although BiH has abundant conventional water resources, the implementation of stormwater harvesting systems in BiH can help reduce the demand on municipal water supply, promote sustainability, and conserve natural water resources. Stormwater harvesting can be utilized for various purposes such as irrigation (crops, lawns, gardens), domestic use (sanitary water, washing clothes), and industrial use (cooling water, cleaning, firefighting) in both rural and urban areas.

Table 8 below lists BiH's wastewater management practices. Unfortunately, no data was found with regards to any reuse practices for treated wastewater nor stormwater.

Table 8: Bosnia and Herzegovina's Wastewater Management Practices Profile.

Characteristic	Value (MCM/yr.)	Reference
Wastewater Generation & Treatment		
Wastewater Inflow to the Public Sewerage System		
Domestic Wastewater (2021)	80.2	[36]
Agricultural Wastewater (2021)	0.2	[36]
Industrial Wastewater (2021)	9.3	[36]
Wastewater from other Activities (2021)	15.2	[36]
Total Wastewater Discharged After Treatment (2021)	38.7	[36]
Total Wastewater Discharged Without Treatment (2021)	66.1	[36]
Industrial Wastewater Inflow to Non-Public Treatment Plants		
NACE Code B - Mining and Quarrying Wastewater (2021)	5.1	[37]
NACE Code C - Manufacturing Wastewater (2021)	47.3	[37]
NACE Code D - Electricity, Gas, Steam and Air Conditioning Supply Wastewater (2021)	12.3	[37]
Total Wastewater Discharged After Treatment (2021)	42.7	[37]
Total Wastewater Discharged Without Treatment (2021)	22.0	[37]
Reuse of Treated Wastewater		
Domestic	No information found/publicly available	
Agricultural	No information found/publicly available	
Industrial	No information found/publicly available	
Reuse of Stormwater		
Domestic	No information found/publicly available	
Agricultural	No information found/publicly available	
Industrial	No information found/publicly available	

1.3. Egypt

Egypt is a transcontinental country located at the northeastern part of Africa and southwestern part of Asia, bordering the Mediterranean Sea to the north, Libya to the west, Sudan to the south, Red Sea to the east, and Palestine/Israel to the northeast (Figure 3).

Figure 3: Map of Egypt [38].

Worldwide, Egypt is currently ranked 31st with regards to total surface area and 15th with regards to population [39]. Table 9 below summarizes selected geographic and demographic data for Egypt.

Table 9: Egypt's Geographic and Demographic Data.

Characteristic	Value	Reference
Total Surface Area (km^2)	1,001,450	[39]
Coastline (km)	2,450	[39]
Population (inhabitants) (2022)	107,770,524	[39]
Population Density (inhabitants/km^2) (2022)	108	Author's Calculation
Total GDP (current US$ Billion) (2021)	404.1	[9]

Egypt is predominantly a desert and can be divided into four main regions: the Nile Valley and Delta, the Western Desert, the Eastern Desert, and the Sinai Peninsula. The most significant of which is the Nile Valley and Delta occupying around 4% of the country's total surface area and containing its only highly fertile lands. Egypt's climate ranges from semiarid in the north to hyperarid in the south and interior with two dominant seasons: a hot summer and a mild winter [40]. Climate projections indicate that Egypt could possibly face more extreme weather in the future with a decrease in precipitation, and an increase in droughts, heatwaves, and sea level. As a result, Egypt's water resources are particularly vulnerable to the effects of climate change due to a likely increase in flow variability of the Nile River, increase in water demand and a decrease in water availability for irrigation, drinking, and energy generation [41].

1.3.1. Water Availability

Egypt is considered a water scarce country with limited water resources. Surface water resources include rivers and lakes. The Nile River is Egypt's only permanent river and is considered vital to the country's security as it supplies around 93% of its annual conventional water resources [42]. The quantity of water allocated for Egypt from the Nile River is controlled by the Nile Water Agreement concluded between Sudan and Egypt in 1959 [43]. Several lakes exist in Egypt with the most prominent being Lake Nasser [44].

Egypt's groundwater water resources include major aquifers such as the Nile, Coastal, Moghra, Fissured Carbonate, Nubian Sandstone, and Hardrock aquifers. These aquifers are non-renewable apart from the Nile Aquifer [43]. Groundwater resource in Egypt face critical challenges such as over abstraction, pollution, and saltwater seepage [44].

Non-conventional water resources include treated wastewater and desalinated seawater. By 2019, Egypt had 455 urban wastewater treatment plants and 52 seawater desalination plants in operation [45]. The majority of the desalination plants are located in North Sinai and along the Red Sea.

According to the United Nations SDG 6.4.2 indicator, level of water stress, Egypt falls above the 100-percentile category, and hence is at *Critical Stress* level [1]. Moreover, the total renewable water resources per capita per year falls between the 500 and 1,000 m^3/capita/yr. category and hence is at *Water Scarcity* status as defined by the Falkenmark water stress index [14].

Table 10 below lists Egypt's available water resources including water stress and scarcity indicators. As can be seen from the table, Egypt has significant conventional water resources; however, it remains classified under water stress conditions due to the high demand. Nevertheless, Egypt is pioneering in the areas of wastewater treatment and desalination to mitigate its future water challenges.

Table 10: Egypt's Water Availability Profile and Water Stress Indicators.

Characteristic	Value	Reference
Conventional Water Resources		
Surface Water (MCM/yr.) (2019)	56,800	[42]
Groundwater (MCM/yr.) (2019)	10,370	[42]
Non-Conventional Water Resources		
Treated Wastewater (MCM/yr.) (2019)	13,510	[42]
Desalinated Seawater (MCM/yr.) (2019)	380	[42]
Water Stress and Scarcity Indicators		
Total Renewable Water Resources per Capita (m^3/capita/yr.) (2019)	573	[17]
Level of Water Stress: Freshwater Withdrawal as a Proportion of Available Freshwater Resources (%) (2019)	141.2	[1]

1.3.2. Water Consumption

In 2019, the total water used across all sectors from both conventional and non-conventional water resources accounted to 81,060 MCM. The percentage of water used by the domestic, agricultural, and industrial sectors was reported as 14.2%, 76.0%, and 6.7%, respectively with the remainder estimated as water lost due to evaporation, 3.1% [42]. In 2020, the United Nations reported under SDG 6.1.1 indicator that the proportion of Egypt's population using at least basic drinking water services stands at 99.4% [4].

In 2020, Egypt's tourism sector contributed 1.3% to the total GDP [19]. No data was found concerning any trends in water usage for the tourism sector. However, Egypt had 3,677,000 foreign arrivals in 2020 [20]. Assuming the typical 150 liters per person per day and an estimated visit of 7 days, water usage can be estimated at 3.9 MCM/yr. It should be noted that the estimate is based on the year 2020, where Egypt's foreign arrivals almost dropped by three-fourths compared to the previous year.

Water consumption among the different industrial sectors can vary significantly and is highly dependent on the type of sector, nature of its operation and the type of finished products. Egypt's major industrial sectors include textiles, food processing, chemicals, pharmaceuticals, hydrocarbons, construction, cement, metals, and light manufactures [39].

Table 11 below lists Egypt's water consumption per sectors. The largest water consumer is the agricultural followed by the domestic and industrial sectors. It should be noted that the data for water consumption for the industrial subsectors is based on an old estimate done in the year 2000. No references were found for recent datasets. However, the same study also assumes that the industrial water consumption for 2017 can be estimated by projecting the data with an increase of 20% [46].

Table 11: Egypt's Water Consumption Profile.

Sector	Value (MCM/yr.)	Reference
Domestic (2019)	11,530	[42]
Tourism (2020)	3.9	Author's Estimation
Agricultural (2019)	61,630	[42]
Industrial (2019)	5,400	[42]
Industrial (2000)	7,499.6	[46]
Food & Beverage (2000)	1,084.0	[46]
Chemical (2000)	674.9	[46]
Primary Metals (2000)	153.3	[46]
Textile (2000)	161.2	[46]
Mining (2020)	106.1	[46]
Power (2000)	5,287.0	[46]
Pulp & Paper	No information found/publicly available	
Other Industrial Sectors (2000)	33.1	[46]

1.3.3. Wastewater Management Practices

In 2020, the United Nations reported under SDG 6.2.1 indicator that the proportion of Egypt's population using safely managed sanitation services stands at 67.1%, which exceeds the average of 42.0% for Northern Africa and Western Asia [5]. As previously mentioned, by 2019 Egypt had 455 urban wastewater treatment plants in operation and was able to treat 74.3% of the total wastewater inflow into the public sewerage system [45]. No data was found regarding the quantities of treated or untreated industrial wastewater inflow to non-public treatment plants.

In 2019, Egypt was able to reuse 13,510 MCM of wastewater in various sectors and applications [42]. The significant value likely includes the treated wastewater from public and non-public treatment plants, and more importantly agricultural drainage [47]. In 2019, 255.5 MCM of treated urban wastewater was reused in the agricultural sector for the irrigation of tree forests [48]. No data was found regarding wastewater reuse in the industrial and domestic sector.

With regards to stormwater, no data was found regarding its capture and reuse. Egypt's mean annual precipitation is estimated at 18.1 mm/yr.; ranked 182nd out of the 182 reported countries worldwide [23]. However, several recent articles have illustrated use-cases for the capture and reuse of stormwater, including pilot scale applications [49], [50], [51]. Based on the study outcomes of [49], the authors estimated that the maximum stormwater that can be harvested from the twenty-two selected cities under investigation stands at 142.5 MCM/yr. The authors concluded that Egypt's northern coast has high potential for stormwater harvesting, while the cities located in the middle and south of the country have insignificant harvesting potential.

Table 12 below shows Egypt's wastewater management practices profile. Unfortunately, no data was found with regards to any reuse practices for stormwater.

Table 12: Egypt's Wastewater Management Practices Profile.

Characteristic	Value (MCM/yr.)	Reference
Wastewater Generation & Treatment		
Wastewater Inflow to the Public Sewerage System		
Total Wastewater Discharged After Treatment (2019)	5,135	[45]
Total Wastewater Discharged Without Treatment (2019)	1,774	[45]
Reuse of Treated Wastewater		
Overall in Various Sectors (2019)	13,510	[42]
Domestic	No information found/publicly available	
Agricultural - Urban Wastewater (2019)	255.5	[48]
Industrial	No information found/publicly available	
Reuse of Stormwater		
Domestic	No information found/publicly available	
Agricultural	No information found/publicly available	
Industrial	No information found/publicly available	

1.4. Lebanon

Lebanon is located in the Levant region of the Middle East in western Asia, bordering Syria to the north and east, and Palestine/Israel to the south. The country's western border consists of a long coastline along the Mediterranean Sea (Figure 4).

Figure 4: Map of Lebanon [52].

Worldwide, Lebanon is currently ranked 168th with regards to total surface area and 122nd with regards to population [53]. Table 13 below summarizes selected geographic and demographic data for Lebanon.

Table 13: Lebanon's Geographic and Demographic Data.

Characteristic	Value	Reference
Total Surface Area (km^2)	10,400	[53]
Coastline (km)	225	[53]
Population (inhabitants) (2022)	5,296,814	[53]
Population Density (inhabitants/km^2) (2022)	509	Author's Calculation
Total GDP (current US$ Billion) (2021)	23.1	[9]

Lebanon topography is mountainous and can be divided into four geographical zones: the coastal plains, the Lebanon Mountains, the Bekaa Valley, and the Anti-Lebanon mountain range. Lebanon's summer climate is hot and dry with low precipitation levels with the coastal plains experiencing high humidity. In the winter, Lebanon's climate is cool and rainy with the mountains experiencing heavy snow [54]. Climate projections indicate that Lebanon could possibly face more extreme weather in the future with an increase in mean annual temperatures, droughts, and sea level and a decrease in precipitation and snow cover. As a result, Lebanon's water resources are particularly vulnerable to the effects of climate change due to a likely increase in evaporation of surface water resources, altered seasonal water regimes due to earlier snow melt, reduction in river flows, and an increased risk of saltwater intrusion at coastal aquifers [54].

1.4.1. Water Availability

Lebanon is considered a water scarce country with ever increasing pressure on water resources resulting from political and regional conflicts. Lebanon's surface water resources include rivers and lakes. Of the 40 rivers that exist, 16 are considered perennial while the rest are seasonal. Lebanon's hydrographic system is divided into five river basins that include the major Litani, El Assi, and Hasbani River Basins. The remaining two include major coastal river basins and minor isolated sub-catchments. On the other hand, several lakes exist in Lebanon such as Yammouneh and Qaysamani Lakes [55].

Around 5,000 springs have been identified in Lebanon. However, not much is known about most of their yields due to the lack of proper monitoring programs. Groundwater resources in Lebanon include two main aquifers, namely the Kesrouane Jurassic (J4) and the Sannine-Maameltain (C4-C5). Lebanon's groundwater resources are vital to the country as they supply the majority of the water needed for irrigation and drinking purposes [55].

Non-conventional water resources include treated wastewater and desalinated seawater. By 2020, Lebanon had 78 urban wastewater treatment plants, most of which are small scale, and some are non-operational [56]. With regards to desalinated seawater, no recent information was found concerning its practice. One source from 2011 lists information on 14 seawater desalination plants commissioned between 1971 and 2001 serving municipalities and power stations [57]. However, the data was not referenced herein due to uncertainties in their current status and old age.

According to the United Nations SDG 6.4.2 indicator, level of water stress, Lebanon falls within the 50 and 75th percentile category, and hence is at *Medium Stress* level [1]. Moreover, the total renewable water resources per capita per year falls between the 500 and 1,000 m^3/capita/yr. category and hence is at *Water Scarcity* status as defined by the Falkenmark water stress index [14].

Table 14 below lists Lebanon's available water resources including water stress and scarcity indicators. As can be seen from the table, Lebanon has significant conventional water resources; however, it remains classified under medium water stress conditions due to the high demand. It should be noted that large discrepancies in the reported values for surface water and groundwater were encountered during the research as was also highlighted in the following references [33], [55], [56], [58]. The discrepancies were described as a direct result of the absence of a unified properly curated database of long-term high quality meteorological and hydrological datasets at the national level [55].

Table 14: Lebanon's Water Availability Profile and Water Stress Indicators.

Characteristic	Value	Reference
Conventional Water Resources		
Surface Water (MCM/yr.) (2020)	2,900	[55]
Groundwater (MCM/yr.) (2020)	1,200	[55]
Non-Conventional Water Resources		
Desalinated Seawater (MCM/yr.) (2019)	47.3	[59]
Water Stress and Scarcity Indicators		
Total Renewable Water Resources per Capita (m^3/capita/yr.) (2019)	657	[17]
Level of Water Stress: Freshwater Withdrawal as a Proportion of Available Freshwater Resources (%) (2019)	58.8	[1]

1.4.2. Water Consumption

The proper evaluation of water use in Lebanon is challenging and is mainly assumed based on typical water consumption figures correlated with demographic data [55]. In 2019, the total water abstraction across all sectors from surface water and groundwater resources accounted to 654.7 MCM and 1,157.3 MCM, respectively [60]. The percentage of water used by the domestic, agricultural, and industrial sectors was reported as 13.0%, 38.0% and 48.9%, respectively. In 2020, the United Nations reported under SDG 6.1.1 indicator that the proportion of Lebanon's population using safely managed drinking water services stands at 47.7%, which significantly lags behind the average of 79.0% for Northern Africa and Western Asia [4].

In 2020, Lebanon's tourism sector contributed 7.5% to the total GDP [19]. No recent data was found concerning any trends in water usage for the tourism sector apart from one source quoting 6.0 MCM in 2010 [55]. Considering that Lebanon had 890,000 foreign arrivals in 2021 [20], and assuming the typical 150 liters per person per day and an estimated visit of 7 days, water usage can be estimated at 0.9 MCM/yr.

Water consumption among the different industrial sectors can vary significantly and is highly dependent on the type of sector, nature of its operation and the type of finished products. Lebanon's major industrial sectors include food processing, wine, jewelry, cement, textiles, mineral and chemical products, wood and furniture products, oil refining, and metal fabricating [53].

Table 15 below lists Lebanon's water consumption per sectors. The largest water consumer is the industrial sector followed by the agricultural and domestic sectors. Unfortunately, no data was found with regards to the water consumption for the industrial subsectors.

Table 15: Lebanon's Water Consumption Profile.

Sector	Value (MCM/yr.)	Reference
Domestic (2019)	240.0	[60]
Tourism (2021)	0.9	Author's Estimation
Agricultural (2019)	700.0	[60]
Industrial (2019)	900.0	[60]
Food & Beverage	No information found/publicly available	
Chemical	No information found/publicly available	
Primary Metals	No information found/publicly available	
Textile	No information found/publicly available	
Mining	No information found/publicly available	
Power	No information found/publicly available	
Pulp & Paper	No information found/publicly available	
Other Industrial Sectors	No information found/publicly available	

1.4.3. Wastewater Management Practices

In 2020, the United Nations reported under SDG 6.2.1 indicator that the proportion of Lebanon's population using safely managed sanitation services stands at 16.3%, which significantly lags behind the average of 42.0% for Northern Africa and Western Asia [5]. As previously mentioned, by 2020 Lebanon had 78 urban wastewater treatment plants, with some rendered non-operational [56]. No recent data was found regarding the quantities of treated wastewater apart from one estimation made in 2010 quoting a total treatment of 8% [55]. Both treated and untreated wastewater generated from various sources is commonly discharged into respective waterbodies. The high percentage of untreated wastewater discharged poses a serious concern with regards to surface water and groundwater pollution [55], [56]. Additionally, no data was found regarding any reuse practices of the treated wastewater.

Due to the current mismanagement of Lebanon's water resource and continued deterioration of water quality and quantity, several initiatives have started to focus on non-conventional water resource such as the capture and reuse of stormwater. Lebanon's mean annual precipitation is estimated at 661.0 mm/yr.; ranked 119th out of the 182 reported countries worldwide [23]. One study reported that Lebanon has the potential to harvest up to 23 MCM of stormwater from building rooftops if only 50% of the rainfall is effectively captured [61].

Storm water harvesting in Lebanon has also caught the eye of international funding where one study piloted 43 stormwater harvesting systems across Lebanon serving residential and institutional buildings. The study concluded that rainwater harvesting has the potential to meet part of, or all, household demand in the winter months [62].

Table 16 below shows Lebanon's wastewater management practices profile. Unfortunately, no data was found with regards to any reuse practices of treated wastewater. With regards to stormwater, research has shown that it is being implemented in small scale applications across Lebanon, but no official numbers on stormwater reuse quantities were found.

Table 16: Lebanon's Wastewater Management Practices Profile.

Characteristic	Value (MCM/yr.)	Reference
Wastewater Generation & Treatment		
Domestic Wastewater (2010)	250.0	[55]
Industrial Wastewater (2010)	60.0	[55]
Total Wastewater Discharged After Treatment (2010)	24.8	[55]
Total Wastewater Discharged Without Treatment (2010)	285.2	[55]
Reuse of Treated Wastewater		
Domestic	No information found/publicly available	
Agricultural	No information found/publicly available	
Industrial	No information found/publicly available	
Reuse of Stormwater		
Domestic (Potential)	23.0	[61]
Domestic (Actual)	No information found/publicly available	
Agricultural	No information found/publicly available	
Industrial	No information found/publicly available	

1.5. Montenegro

Montenegro is located at the western side of the Balkan Peninsula in southeastern Europe, bordering Croatia to the northwest, Bosnia and Herzegovina to the north, Serbia to the northeast, Kosovo to the east and Albania to the southeast. The majority of the country's western border is a coastline along the Adriatic Sea (Figure 5).

Figure 5: Map of Montenegro [63].

Worldwide, Montenegro is currently ranked 161st with regards to total surface area and 171st with regards to population [64]. Table 17 below summarizes selected geographic and demographic data for Montenegro.

Table 17: Montenegro Geographic and Demographic Data.

Characteristic	Value	Reference
Total Surface Area (km^2)	13,812	[64]
Coastline (km)	294	[64]
Population (inhabitants) (2022)	604,966	[64]
Population Density (inhabitants/km^2) (2022)	44	Author’s Calculation
Total GDP (current US$ Billion) (2021)	5.9	[9]

Montenegro's topography is predominantly hilly and mountainous and can be divided into four geographic zones: the narrow coastal plain, the high Dinaric mountain range, the central Montenegrin depression, and the high northern Montenegrin mountain range [65]. Montenegro's climate generally varies with its topography and is described as Mediterranean with hot dry summers and autumns and relatively cold winters accompanied with heavy snowfall at the inlands [64]. Climate projections indicate that Montenegro could possibly face more extreme weather in the future with increased temperatures, floods, droughts, forest fires, heatwaves and a likely decrease in precipitation. As a result, Montenegro's water resources are particularly vulnerable to the effects of climate change due to a likely increase in summer water usage, a decrease in water quality, a decrease in average annual yields of rechargeable systems, a decrease in groundwater table levels, and an increase in peak runoff causing floods [66].

1.5.1. Water Availability

Montenegro is abundant in conventional water resources. Two basins exist in Montenegro, namely the Black Sea (Danube) Basin (54.6% of territory) and the Adriatic Sea Basin (45.4% of the territory) [65]. Surface water resources include rivers and lakes. The main rivers within the Adriatic Sea Basin are the Moraca, Zeta, Cijevna and Bojana Rivers, and within the Danube River Basin, the Piva, Tara, Lim, Ibar and Cehotina Rivers [67]. More than 20 large lakes exist in Montenegro, six of which are glacial. The most prominent of these is the transboundary Lake Skadar which Montenegro shares with Albania [65].

Groundwater resources in Montenegro are found in various geological formations dating from Paleozoic to Quaternary era [66]. Most of the groundwater levels in Montenegro are deep, with several exceptions (e.g., coastal area, Lake Skadar depression, etc.). Karstic aquifers that exist along the Adriatic coast to the northeastern border of Montenegro can hold substantial water yields. Montenegro's groundwater resources are vital to the country as they are the main source of drinking water [65].

Non-conventional water resources include treated wastewater. By 2015, Montenegro had 5 urban wastewater treatment plants in operation [65]. Additionally, the same report mentions 8 that are under construction, 6 that are awarded, and 5 under public tendering phase. With regards to desalinated seawater, no information was found concerning its practice in Montenegro, which may be due to the country's reliance on the abundant conventional water resources.

No data was reported for Montenegro under the United Nations SDG 6.4.2 indicator, level of water stress, due to the lack of data required for its assessment [1]. However, due to the apparent abundance in renewable water resources, Montenegro can be safely assumed to fall within the *No Stress* level. Moreover, the total renewable water resources per capita per year is way above the 1700 m^3/capita/yr. threshold for water stress as defined by the Falkenmark water stress index [14].

Table 18 below lists Montenegro's available water resources including water stress and scarcity indicators. As can be seen from the table, Montenegro has abundant conventional water resources and can be classified under no water stress conditions. Nevertheless, several sources have raised concerns with regards to Montenegro's future water stability due to the risks of climate change and water resource pollution [64], [65], [66].

It should be noted that the reported data below for the available conventional water resources in Montenegro were difficult to find, even in reputable databases. The reported data according to the article are based on a national source estimate [68].

Table 18: Montenegro's Water Availability Profile and Water Stress Indicators.

Characteristic	Value	Reference
Conventional Water Resources		
Surface Water (MCM/yr.) (2015)	12,700	[68]
Groundwater (MCM/yr.) (2015)	3,000	[68]
Non-Conventional Water Resources		
Desalinated Seawater (MCM/yr.)	No information found/publicly available	
Water Stress and Scarcity Indicators		
Total Renewable Water Resources per Capita (m^3/capita/yr.) (2015)	25,080	[68]
Level of Water Stress: Freshwater Withdrawal as a Proportion of Available Freshwater Resources (%)	No information found/publicly available	

1.5.2. Water Consumption

In 2020, the total water abstraction by the entities managing public water supply from surface water and groundwater resources accounted to 1.9 MCM and 97.3 MCM, respectively, while 22.1 MCM was acquired from other water supply systems [69]. 38.6% of the total water was reported as delivered to end-users, while the remaining 61.4% was reported as losses in the water mains. The percentage of delivered water to the domestic and industrial sectors was reported as 98.3% and 1.7%, respectively. In 2020, the United Nations reported under SDG 6.1.1 indicator that the proportion of Montenegro's population using safely managed drinking water services stands at 85.1%, which slightly lags behind the average of 96.0% for Europe and Northern America [4].

In 2020, Montenegro's tourism sector contributed 3.8% to the total GDP [19]. No data was found concerning any trends in water usage for the tourism sector. However, one report highlights that during the summer touristic season, the local water supply at the coastal area almost reaches its limits [65]. Considering that Montenegro had 1,554,000 foreign arrivals in 2021 [20], and assuming the typical 150 liters per person per day and an estimated visit of 7 days, water usage can be estimated at 1.6 MCM/yr.

Water consumption among the different industrial sectors can vary significantly and is highly dependent on the type of sector, nature of its operation and the type of finished products. Montenegro's major industrial sectors include steelmaking, aluminum, agricultural processing, and production of consumer goods [64].

Table 19 below lists Montenegro's water consumption per sectors. The largest water consumer from the public water supply is the domestic sector followed by the industrial sector. It should also be noted that the water used by the agricultural sector is almost exclusively sourced from groundwater, 99.9% [69].

Table 19: Montenegro's Water Consumption Profile.

Sector	Value (MCM/yr.)	Reference
Tourism (2021)	1.6	Author's Estimation
Water Consumed from the Public Water Supply		
Domestic (2020)	46.0	[69]
Agricultural	No information found/publicly available	
Industrial (2020)	0.80	[69], [70]
Food & Beverage (2020)	0.44	[69], [70]
Chemical	No information found/publicly available	
Primary Metals (2020)	0.02	[69], [70]
Textile	No information found/publicly available	
Mining (2020)	0.04	[69], [70]
Power (2020)	0.07	[69], [70]
Pulp & Paper	No information found/publicly available	
Other Industrial Sectors (2020)	0.24	[69], [70]
Water Consumed from Own Supply (Direct Surface Water and Groundwater)		
Domestic	No information found/publicly available	
Agricultural (2020)	7.4	[69]
Industrial (2020)	3.1	[69], [70]
Food & Beverage (2020)	0.25	[69], [70]
Chemical	No information found/publicly available	
Primary Metals (2020)	2.45	[69], [70]
Textile	No information found/publicly available	
Mining (2020)	0.44	[69], [70]
Power	No information found/publicly available	
Pulp & Paper	No information found/publicly available	
Other Industrial Sectors	No information found/publicly available	

1.5.3. Wastewater Management Practices

In 2020, the United Nations reported under SDG 6.2.1 indicator that the proportion of Montenegro's population using safely managed sanitation services stands at 45.4%, which significantly lags behind the average of 78.0% for Europe and Northern America [5]. As previously mentioned, by 2015 Montenegro had 5 urban wastewater treatment plants in operation with several new facilities in the pipeline [65]. In 2020, Montenegro was able to treat 78.8% of the wastewater inflow into the public sewerage system [69] and 55.3% of the industrial wastewater inflow to non-public treatment plants [70]. However, no data was found regarding any reuse practices of the treated wastewater.

With regards to stormwater, no data was found regarding its capture and reuse nor any use-case articles. Montenegro's annual precipitation is very uneven, ranging from 800 mm in the north to about 5,000 mm in the southwest [66]. Although Montenegro has abundant conventional water resources, the implementation of stormwater harvesting systems in Montenegro can help reduce the demand on municipal water supply, promote sustainability, and conserve natural water resources. Stormwater harvesting can be utilized for various purposes such as irrigation (crops, lawns, gardens), domestic use (sanitary water, washing clothes), and industrial use (cooling water, cleaning, firefighting) in both rural and urban areas.

Table 20 below shows Montenegro's wastewater management practices profile. Unfortunately, no data was found with regards to any reuse practices for treated wastewater nor stormwater.

Table 20: Montenegro's Wastewater Management Practices Profile.

Characteristic	Value (MCM/yr.)	Reference
Wastewater Generation & Treatment		
Wastewater Inflow to the Public Sewerage System		
Domestic Wastewater (2020)	26.24	[69]
Total Wastewater Discharged After Treatment (2020)	20.67	[69]
Total Wastewater Discharged Without Treatment (2020)	5.57	[69]
Industrial Wastewater Inflow to Non-Public Treatment Plants		
NACE Code B - Mining and Quarrying Wastewater (2020)	0.06	[70]
NACE Code C - Manufacturing Wastewater (2020)	2.97	[70]
NACE Code D - Electricity, Gas, Steam and Air Conditioning Supply Wastewater (2020)	0.70	[70]
Total Wastewater Discharged After Treatment (2020)	2.06	[69]
Total Wastewater Discharged Without Treatment (2020)	1.66	[69]
Reuse of Treated Wastewater		
Domestic	No information found/publicly available	
Agricultural	No information found/publicly available	
Industrial	No information found/publicly available	
Reuse of Stormwater		
Domestic	No information found/publicly available	
Agricultural	No information found/publicly available	
Industrial	No information found/publicly available	

1.6. Morocco

Morocco is located at the western side of the Maghreb region in northern Africa, bordering Algeria to the east and the disputed Western Sahara to the south. Morocco overlooks the Mediterranean Sea to the north and the Atlantic Ocean to the west (Figure 6).

Figure 6: Map of Morocco [71].

Worldwide, Morocco is currently ranked 41st with regards to total surface area and 40th with regards to population [72]. Table 21 below summarizes selected geographic and demographic data for Morocco.

Table 21: Morocco's Geographic and Demographic Data.

Characteristic	Value	Reference
Total Surface Area (km^2)	716,550	[72]
Coastline (km)	2,945	[72]
Population (inhabitants) (2022)	36,738,229	[72]
Population Density (inhabitants/km^2) (2022)	51	Author's Calculation
Total GDP (current US$ Billion) (2021)	142.9	[9]

Morocco is largely hilly and mountainous with distinct regions across its territory which include the Rif Mountains in the north, the Atlas Mountains in the center, plateaus in the east, plains and coast in the west, and desert in the south [73]. The majority of Morocco, especially the coast, has a typical Mediterranean climate with mild wet winters and hot dry summers. Further inland, Morocco's climate gets more severe, colder at the mountains and hotter closer to the Sahara Desert [74]. Climate projections indicate that Morocco could possibly face more extreme weather in the future with a decrease in precipitation and snowpack, and an increase in temperatures, droughts, heatwaves, and sea level. As a result, Morocco's water resources are particularly vulnerable to the effects of climate change due to a likely reduction in stream flows, shift in seasonal water availability, earlier snowmelt, increased dependence on groundwater, and increased pollution of surface waters [73].

1.6.1. Water Availability

Morocco is considered a water scarce country. Conventional water resources include surface water (rivers and lakes) and groundwater. These resources are geographically divided according to their respective basins and are managed by 10 agencies referred to as Agence du Bassin Hydraulique (ABH), which include the: Loukkos, Moulouya, Sebbou, Bouregreg et Chaouia, Oum Rbia, Tensift, Souss-Massa; Draa; Ziz-Gheriss-Guir, and Saharan Basins [75].

Morocco's basins are characterized by uneven distribution of conventional water resources with respect to space and time [74]. Surface water resources vary from an order of millions to billions depending on the ABH location. For example, in 2019 the top two were Sebbou and Loukkos Basins with 2,656 MCM and 2,057 MCM, respectively, while the bottom two were the Souss-Massa and Saharan Basins with 66 MCM and 23 MCM, respectively [76]. Consequently, the Sebbou and Loukkos Basins contain almost 50% of the surface water while the other 8 basins contain the rest [76].

Groundwater resources are found in various geological formations across Morocco and include fractured rocks, weathered rocks, karst, among others [75]. Morocco's groundwater resources are estimated to be held within 32 deep and 98 shallow aquifers. The deeper aquifers are mostly inaccessible due to the economics of drilling while the shallower ones are facing major risks from over abstraction, climate change and pollution [75].

Non-conventional water resources include treated wastewater and desalinated seawater. By 2016, Morocco had 131 urban wastewater treatment plants [77] and 15 desalination plants in operation [78]. Morocco has recognized its future water resource challenges and has put in place strategic plans and investments to expand the utilization of non-conventional water resources to mitigate the current pressures on conventional ones [77], [79].

According to the United Nations SDG 6.4.2 indicator, level of water stress, Morocco falls within the 50 and 75th percentile category, and hence is at *Medium Stress* level [1]. Moreover, the total renewable water resources per capita per year falls between the 500 and 1,000 m^3/capita/yr. category and hence is at *Water Scarcity* status as defined by the Falkenmark water stress index [14].

Table 22 below lists Morocco's available water resources including water stress and scarcity indicators. As can be seen from the table, Morocco has significant conventional water resources; however, it remains classified under medium water stress conditions due to the high demand.

Table 22: Morocco's Water Availability Profile and Water Stress Indicators.

Characteristic	Value	Reference
Conventional Water Resources		
Surface Water (MCM/yr.) (2019)	9,453	[76]
Groundwater (MCM/yr.) (2019)	4,000	[76]
Non-Conventional Water Resources		
Treated Wastewater (MCM/yr.) (2016)	109.9	[77]
Desalinated Seawater (MCM/yr.) (2016)	132.0	[78]
Water Stress and Scarcity Indicators		
Total Renewable Water Resources per Capita (m^3/capita/yr.) (2019)	795	[17]
Level of Water Stress: Freshwater Withdrawal as a Proportion of Available Freshwater Resources (%) (2019)	50.8	[1]

1.6.2. Water Consumption

In 2019, the total water abstraction across all sectors from surface water and groundwater resources accounted to 8,251 MCM and 2,322 MCM, respectively [60]. The largest water abstracter was the agricultural sector followed by the domestic and industrial sectors, with 87.8%, 10.2% and 2.0%, respectively. In 2020, the United Nations reported under SDG 6.1.1 indicator that the proportion of Morocco’s population using safely managed drinking water services stands at 80.0% which is higher than the average of 79.0% for Northern Africa and Western Asia [4].

In 2020, Morocco’s tourism sector contributed 3.7% to the total GDP [19]. No data was found concerning any trends in water usage for the tourism sector. However, Morocco had 3,722,000 foreign arrivals in 2021 [20]. Assuming the typical 150 liters per person per day and an estimated visit of 7 days, water usage can be estimated at 3.9 MCM/yr.

Water consumption among the different industrial sectors can vary significantly and is highly dependent on the type of sector, nature of its operation and the type of finished products. Morocco’s major industrial sectors include automotive parts, phosphate mining and processing, aerospace, food processing, leather goods, textiles, construction, and energy [72].

Table 23 below lists Morocco’s water consumption per sectors. The largest water consumer is the agricultural sector followed by the domestic and industrial sectors. Unfortunately, no data was found with regards to water usage per industrial subsector.

Table 23: Morocco's Water Consumption Profile.

Sector	Value (MCM/yr.)	Reference
Domestic (2019)	1,063	[60]
Tourism (2021)	3.9	Author's Estimation
Agricultural (2019)	9,156	[60]
Industrial (2019)	212	[60]
Food & Beverage	No information found/publicly available	
Chemical	No information found/publicly available	
Primary Metals	No information found/publicly available	
Textile	No information found/publicly available	
Mining	No information found/publicly available	
Power	No information found/publicly available	
Pulp & Paper	No information found/publicly available	
Other Industrial Sectors	No information found/publicly available	

1.6.3. Wastewater Management Practices

In 2020, the United Nations reported under SDG 6.2.1 indicator that the proportion of Morocco's population using safely managed sanitation services stands at 39.3%, which slightly lags behind the average of 42.0% for Northern Africa and Western Asia [5]. As previously mentioned, by 2016 Morocco had 131 urban wastewater treatment plants in operation was able to treat 25.3% of the total generated wastewater from all sectors [77].

With regards to treated wastewater reuse, Morocco was able to reuse 41.0% of the treated wastewater in 2016. Reuse activities include, irrigation of green spaces, parks and golf courses, agricultural purposes, industrial use in phosphate mining and groundwater recharge, with 67.8%, 12.8%, 16.7% and 2.7%, respectively [77].

With regards to stormwater, no data was found regarding its capture and reuse. Morocco's mean annual precipitation is estimated at 346 mm/yr.; ranked 153rd out of the 182 reported countries worldwide [23]. One use-case study estimated that 121,954 m^3 of water can be saved per year if stormwater harvesting was implemented in the residential area of Hay Essalama and Nakhil with 2,200 apartments buildings and Hay Atlas with 200 villa buildings [80].

Table 24 below shows Morocco's wastewater management practices profile. Unfortunately, no data was found with regards to any reuse practices for stormwater.

Table 24: Morocco's Wastewater Management Practices Profile.

Characteristic	Value (MCM/yr.)	Reference
Wastewater Generation & Treatment		
Total Wastewater Discharged After Treatment (2016)	267.9	[77]
Total Wastewater Discharged Without Treatment (2016)	792.0	[77]
Reuse of Treated Wastewater		
Irrigation of Golf Course + Parks (2016)	74.5	[77]
Agricultural (2016)	14.0	[77]
Industrial (2016)	18.4	[77]
Groundwater Recharge (2016)	3.0	[77]
Reuse of Stormwater		
Domestic	No information found/publicly available	
Agricultural	No information found/publicly available	
Industrial	No information found/publicly available	

1.7. Tunisia

Tunisia is located in the Maghreb region in northern Africa, bordering Algeria to the west and southwest and Libya to the southeast. Tunisia overlooks the Mediterranean Sea to the north and east (Figure 7).

Figure 7: Map of Tunisia [81].

Worldwide, Tunisia is currently ranked 93rd with regards to total surface area and 80th with regards to population [82]. Table 25 below summarizes selected geographic and demographic data for Tunisia.

Table 25: Tunisia Geographic and Demographic Data.

Characteristic	Value	Reference
Total Surface Area (km^2)	163,610	[82]
Coastline (km)	1,148	[82]
Population (inhabitants) (2022)	11,896,972	[82]
Population Density (inhabitants/km^2) (2022)	73	Author's Calculation
Total GDP (current US$ Billion) (2021)	46.7	[9]

Tunisia's is largely hilly with several mountainous ranges. Its climate varies with the topography which can be divided into three distinct regions: the northern mountainous region which experiences Mediterranean climate with mild rainy winters and hot dry summers; the south which experiences hot dry and semiarid climate as it approaches the Sahara Desert; and the eastern coastal border which experiences an arid steppe climate [83]. Climate projections indicate that Tunisia could possibly face more extreme weather in the future with a decrease in precipitation and an increase in temperatures, droughts, floods, and sea level. As a result, Tunisia's water resources are particularly vulnerable to the effects of climate change due to a likely increase in salinization of aquifers, damage to water supply and distribution infrastructure and increase in the risks of water resource pollution [83].

1.7.1. Water Availability

Tunisia is considered a water scarce country. Water resources are unevenly distributed across the territory with noticeable seasonal variations. This is especially apparent when comparing the water rich north and the semi-arid south [84]. Tunisia's surface water resources are distributed across several river basins which include: bassin de la Mejerda; Extrême-Nord; Ichkeul et Bizerte; Cap Bon et Meliane; Zéroud-Merguellil, Sahel de Sousse et de Sfax; and bassin des chotts et Djeffara [85].

Groundwater resources in Tunisia are found in various geological formations. Tunisia's groundwater resources are held in both shallow and deep aquifers across the country. In the north, the aquifers are generally shallow and renewable, while in the south they are mostly deep and non-renewable [85]. Tunisian groundwater resources are particularly at risk due to overexploitation, significant drop in water level and increased salinization [84], [85].

Non-conventional water resources include treated wastewater and desalinated seawater. By 2021, Tunisia had 125 urban wastewater treatment plants in operation, 60 of which are concerned with the reuse of treated wastewater [86]. On the other hand, in 2020, Tunisia had 21 desalination plants with 60% of the total capacity reserved for drinking water generation [78].

According to the United Nations SDG 6.4.2 indicator, level of water stress, Tunisia falls within the 75 and 100th percentile category, and hence is at *High Stress* level [1]. Moreover, the total renewable water resources per capita per year falls below the 500 m^3/capita/yr. category and hence is at *Absolute Scarcity* status as defined by the Falkenmark water stress index [14].

Table 26 below lists Tunisia's available water resources including water stress and scarcity indicators. As can be seen from the table, Tunisia has significant conventional water resources; however, it remains classified under high water stress conditions due to the high demand.

Table 26: Tunisia's Water Availability Profile and Water Stress Indicators.

Characteristic	Value	Reference
Conventional Water Resources		
Surface Water (MCM/yr.) (2019)	2,100	[87]
Groundwater (MCM/yr.) (2019)	2,196	[87]
Non-Conventional Water Resources		
Treated Wastewater (MCM/yr.) (2021)	63.5	[86]
Desalinated Seawater (MCM/yr.) (2020)	91.3	[78]
Water Stress and Scarcity Indicators		
Total Renewable Water Resources per Capita (m^3/capita/yr.) (2019)	395	[17]
Level of Water Stress: Freshwater Withdrawal as a Proportion of Available Freshwater Resources (%) (2019)	96.0	[1]

1.7.2. Water Consumption

In 2019, the total water abstraction across all sectors from surface water and groundwater resources accounted to 1,046 MCM and 2,747 MCM, respectively [60]. The largest water abstracter was the agricultural sector followed by the domestic and industrial sectors with 76.4%, 21.9% and 1.8%, respectively. In 2020, the United Nations reported under SDG 6.1.1 indicator that the proportion of Tunisia's population using safely managed drinking water services stands at 79.3% which is on par with the average of 79.0% for Northern Africa and Western Asia [4].

In 2020, Tunisia's tourism sector contributed 2.4% to the total GDP [19]. No data was found concerning any trends in water usage for the tourism sector. However, Tunisia had 2,475,000 foreign arrivals in 2021 [20]. Assuming the typical 150 liters per person per day and an estimated visit of 7 days, water usage can be estimated at 2.6 MCM/yr.

Water consumption among the different industrial sectors can vary significantly and is highly dependent on the type of sector, nature of its operation and the type of finished products. Tunisia's major industrial sectors include petroleum, mining (particularly phosphate and iron ore), textiles, footwear, agribusiness, and beverages [82].

Table 27 below lists Tunisia's water consumption per sectors. The largest water consumer is the agricultural sector followed by the domestic and industrial sectors. Unfortunately, no data was found regarding the water consumption per industrial subsector.

Table 27: Tunisia's Water Consumption Profile.

Sector	Value (MCM/yr.)	Reference
Domestic (2019)	839	[60]
Tourism (2021)	2.6	Author's Estimation
Agricultural (2019)	2,933	[60]
Industrial (2019)	68	[60]
Food & Beverage	No information found/publicly available	
Chemical	No information found/publicly available	
Primary Metals	No information found/publicly available	
Textile	No information found/publicly available	
Mining	No information found/publicly available	
Power	No information found/publicly available	
Pulp & Paper	No information found/publicly available	
Other Industrial Sectors	No information found/publicly available	

1.7.3. Wastewater Management Practices

In 2020, the United Nations reported under SDG 6.2.1 indicator that the proportion of Tunisia's population using safely managed sanitation services stands at 80.8%, which exceptionally exceeds the average of 42.0% for Northern Africa and Western Asia [5]. As previously mentioned, by 2021 Tunisia had 125 urban wastewater treatment plants in operation and was able to treat 99.2% of the total generated wastewater from all sectors [86].

In 2021, Tunisia had 60 wastewater treatment plants dedicated for reuse purposes. Of the 288.5 MCM of treated wastewater, Tunisia generated 22.0% treated wastewater for direct and indirect reuse purposes. Direct reuse involves activities in agriculture and irrigation of golf courses and green space with 66.1%, 29.9%, and 4%, respectively [86].

With regards to stormwater, no data was found regarding its capture and reuse. Tunisia's mean annual precipitation is estimated at 207 mm/yr., ranked 167th out of the 182 reported countries worldwide [23]. One use-case study utilized roof masonry cisterns for rainwater collection [88]. The study concluded that the collected rainwater had significant microbial contamination rendering it not suitable for drinking purposes; unless properly disinfected. Nonetheless, the quality was good enough for irrigation.

Table 28 below shows Tunisia's wastewater management practices profile. Unfortunately, no data was found with regards to any reuse practices for stormwater.

Table 28: Tunisia's Wastewater Management Practices Profile.

Characteristic	Value (MCM/yr.)	Reference
Wastewater Generation & Treatment		
Total Wastewater Discharged After Treatment (2021)	288.5	[86]
Total Wastewater Discharged Without Treatment (2021)	2.3	[86]
Reuse of Treated Wastewater		
Direct Reuse		
Agricultural (2021)	14.4	[86]
Irrigation of Golf Courses (2021)	6.5	[86]
Irrigation of Green Space (2021)	0.9	[86]
Indirect Reuse		
Discharge into Waterbodies/Aquifers (2021)	41.7	[86]
Reuse of Stormwater		
Domestic	No information found/publicly available	
Agricultural	No information found/publicly available	
Industrial	No information found/publicly available	

1.8. Türkiye

Türkiye is a transcontinental country located at the western side of Asia and southeastern side of Europe, bordering Georgia to the northeast; Armenia, Azerbaijan, and Iran to the east; Iraq to the southeast; Syria to the south; and Greece and Bulgaria to the northwest. Türkiye overlooks the Black Sea to the north; Mediterranean Sea to the south and Aegean Sea to the west (Figure 8).

Figure 8: Map of Türkiye [89].

Worldwide, Türkiye is currently ranked 38th with regards to total surface area and 19th with regards to population [90]. Table 29 below summarizes selected geographic and demographic data for Türkiye.

Table 29: Türkiye's Geographic and Demographic Data.

Characteristic	Value	Reference
Total Surface Area (km^2)	783,562	[90]
Coastline (km)	7,200	[90]
Population (inhabitants) (2022)	83,047,706	[90]
Population Density (inhabitants/km^2) (2022)	106	Author’s Calculation
Total GDP (current US$ Billion) (2021)	819.0	[9]

Due to its topography, Türkiye has several climatic zones. At the southern costal side, Türkiye experiences Mediterranean climate with hot dry summers and mild rainy winters. The Black Sea climate is mild and rainy in almost all seasons. Central Anatolia features a steppe climate with little precipitation with temperatures varying due to the surrounding high mountains [91]. Climate projections indicate that Türkiye could possibly face more extreme weather in the future with variations in extreme temperature, decrease in precipitation, and increase in desertification, flooding, and sea level. As a result, Türkiye's water resources are particularly vulnerable to the effects of climate change due to a likely decline in the available water in the basins and an increase in saltwater intrusion [91].

1.8.1. Water Availability

Türkiye is abundant in conventional water resources and is divided into 25 hydrological basins with the rivers often experiencing irregular regimes. The top three basins with regards to average annual flow are the Fırat-Dicle, Doğu Karadeniz and Antalya Basins, respectively [92]. Türkiye's longest rivers, the Kizilirmak, the Yesilirmak and the Sakarya, flow into the Black Sea. The Dicle and Firat Rivers originate in Eastern Anatolia and flow south into the Persian Gulf [93].

Non-conventional water resources include treated wastewater and desalinated seawater. By 2016, Türkiye had 1,015 domestic wastewater treatment plants either in operation or under construction, with only 15 concerned with the reuse of treated wastewater [94]. On the other hand, Türkiye had 59 desalination plants in 2011 treating water from various sources including 92.5% seawater, 6.7% brackish water, and the remainder from rivers and wastewater [95].

According to the United Nations SDG 6.4.2 indicator, level of water stress, Türkiye falls within the 25 and 50th percentile category, and hence is at *Low Stress* level [1]. Moreover, the total renewable water resources per capita per year is way above the 1700 m^3/capita/yr. threshold for water stress as defined by the Falkenmark water stress index [14].

Table 30 below lists Türkiye's available water resources including water stress and scarcity indicators. As can be seen from the table, Türkiye has abundant conventional water resources; however, it remains classified under low water stress conditions due to the high demand.

Table 30: Türkiye's Water Availability Profile and Water Stress Indicators.

Characteristic	Value	Reference
Conventional Water Resources		
Surface Water (MCM/yr.) (2021)	185,370	[92]
Groundwater (MCM/yr.) (2021)	17,815	[92]
Non-Conventional Water Resources		
Treated Wastewater (MCM/yr.) (2017)	29.6	[94]
Desalinated Seawater (MCM/yr.) (2011)	171.1	[95]
Water Stress and Scarcity Indicators		
Total Renewable Water Resources per Capita (m^3/capita/yr.) (2019)	2,536	[17]

Characteristic	Value	Reference
Level of Water Stress: Freshwater Withdrawal as a Proportion of Available Freshwater Resources (%) (2019)	45.7	[1]

1.8.2. Water Consumption

In 2018, the total water abstraction across all sectors from surface water and groundwater resources accounted to 44,914 MCM and 16,180 MCM, respectively [18]. 91.9% of the abstracted surface water was utilized by the agricultural sector, while 20.6% of the abstracted groundwater was utilized by the domestic sector. In 2020, the United Nations reported under SDG 6.1.1 indicator that the proportion of Türkiye's population using at least basic drinking water services stands at 97.0% [4].

In 2020, Türkiye's tourism sector contributed 1.9% to the total GDP [19]. No data was found concerning any trends in water usage for the tourism sector. However, Türkiye had 30,039,000 foreign arrivals in 2021 [20]. Assuming the typical 150 liters per person per day and an estimated visit of 7 days, water usage can be estimated at 31.5 MCM/yr.

Water consumption among the different industrial sectors can vary significantly and is highly dependent on the type of sector, nature of its operation and the type of finished products. Türkiye's major industrial sectors include textiles, food processing, automobiles, electronics, mining (coal, chromate, copper, boron), steel, petroleum, lumber, and paper [90].

Table 31 below lists Türkiye's water consumption per sectors. The largest water consumer is the agricultural sector followed by the domestic and industrial sectors.

Table 31: Türkiye's Water Consumption Profile.

Sector	Value (MCM/yr.)	Reference
Domestic (2018)	6,649	[18]
Tourism (2021)	31.5	Author's Estimation
Agricultural (2018)	51,735	[18]
Industrial (2018)	5,034.6	[21]
Food & Beverage (2018)	123.6	[21]
Chemical (2018)	447.2	[21]
Primary Metals (2018)	1864.9	[21]
Textile (2018)	230.2	[21]
Mining	No information found/publicly available	
Power	No information found/publicly available	
Pulp & Paper (2018)	32.2	[21]
Other Industrial Sectors (2018)	2336.5	[21]

1.8.3. Wastewater Management Practice

In 2020, the United Nations reported under SDG 6.2.1 indicator that the proportion of Türkiye's population using safely managed sanitation services stands at 78.4%, which is on par with the average of 78.0% for Europe and Northern America [5]. As previously mentioned, by 2016, Türkiye had 1,015 domestic wastewater treatment plants either in operation or under construction and in 2018 was able to treat 88.3% of the total generated wastewater from urban sources [96].

With regards to stormwater, no data was found regarding its capture and reuse. Türkiye's mean annual precipitation is estimated at 593 mm/yr.; ranked 133rd out of the 182 reported countries worldwide [23]. Several recent articles have illustrated use-cases for the capture and reuse of stormwater in household and commercial buildings and in industrial sites [97], [98], [99]. According to [97], the authors estimated that as much as 13% of the needed water for the population of three major districts in Izmir can be obtained with the implementation of stormwater harvesting systems in public and commercial building. Similarly, according to [99], the authors estimated that 56,388 m^3/yr. of stormwater can be collected at the photovoltaic power plants in Çorum.

In 2021, the Turkish Ministry of Environment and Urbanization has mandated the installation of rainwater harvesting systems on rooftops of new buildings. The amendments to the Zoning Regulations state that all buildings constructed on land plots exceeding 2,000 m^2 must have rainwater collection systems. The collected water will be stored underground and utilized for irrigation and maintenance of surrounding areas such as green spaces. This initiative aims to address the increasing issue of drought and promote sustainable water management practices in Türkiye [100].

Table 32 below shows Türkiye's wastewater management practices profile. Unfortunately, no data was found with regards to any reuse practices for stormwater.

Table 32: Türkiye Wastewater Management Practices Profile.

Characteristic	Value (MCM/yr.)	Reference
Wastewater Generation & Treatment		
Urban Wastewater (2018)	4,795	[96]
Total Wastewater Discharged After Treatment (2018)	4,236	[96]
Total Wastewater Discharged Without Treatment (2018)	559	[96]
Reuse of Treated Wastewater		
Urban – Green Area Irrigation (2017)	0.8	[94]
Environmental/Ecological Use (2017)	4.8	[94]
Industrial (2017)	16.8	[94]
Reuse in Wastewater Treatment Plants – Green Area Irrigation, Processes, Washing (2017)	1.9	[94]
Other Uses (2017)	5.3	[94]

Characteristic	Value (MCM/yr.)	Reference
Reuse of Stormwater		
Domestic	No information found/publicly available	
Agricultural	No information found/publicly available	
Industrial	No information found/publicly available	

2. Sector-Specific Wastewater Characteristics

Sections 2.1 to 2.7 were developed to provide a general overview of the industrial sectors under investigation, their typical water consumption figures, typical wastewater characteristics (the identified major contaminants are also populated in Appendix A), and wastewater treatment techniques and practices commonly applied within their wastewater treatment schemes.

Identification of conventional treatment techniques and practices for the sector under investigation was performed by analyzing the major contaminants that need to be treated (as per Appendix A) and matching them with the longlist of treatment techniques developed in Appendix B, which summarizes common treatment techniques in the market and the major target contaminant they are able to efficiently remove. BREFs were also thoroughly reviewed for the identification of BATs and BMPs. For the case of BMPs, a general water and wastewater related BMP longlist was developed as detailed in Appendix C, which is applicable to all sectors. Appendix C was used to capture the BMPs in general form which were later tailor made to the specifics of the sector under investigation.

2.1. Food & Beverage

The Food & Beverage (F&B) sector is a highly diverse and fragmented sector utilizing a wide range of raw materials to produce a diverse variety of final products. In 2020, the EU-27 had an estimate of 291,511 F&B enterprises employing 4,251,023 individuals with a total estimated turnover of 1,085.6 billion Euros [101].

According to NACE Code C Manufacturing Subcodes C10 and C11, the F&B sector is categorized into 10 divisions and 32 subdivisions [102]. F&B divisions include:

- Processing and preserving of meat and production of meat products
- Processing and preserving of fish, crustaceans, and mollusks
- Processing and preserving of fruit and vegetables
- Manufacture of vegetable and animal oils and fats
- Manufacture of dairy products
- Manufacture of grain mill products, starches, and starch products
- Manufacture of bakery and farinaceous products
- Manufacture of other food products
- Manufacture of prepared animal feeds
- Manufacture of beverages

2.1.1. Water Consumption

Water consumption in the F&B sector is highly variable and depends on several factors such as the nature of raw materials and finished products, manufacturing process, equipment, cleaning procedures, facilities capacity for water reuse, among others. In 2019, the global water consumption of the F&B sector accounted to 87.4 BCM; without considering the water used for animal and crop growing [103].

In general, water in the F&B sector is consumed in a variety of activities such as [104]:

- Food processing, where the water either comes in contact with or is added to the product
- Water which does not come in contact with the product, e.g., boilers, cooling circuits, refrigeration, chillers, air conditioning and heating, water used for product pasteurization
- Washing of raw materials
- Equipment and installation cleaning
- Cleaning of packaging materials
- Firefighting

Table 33 below lists typical water consumption values for several F&B divisions. It should be noted that F&B divisions have several subdivisions, e.g., the dairy division has subdivisions such as market milk, fermented milk, cheese, powder, among others, each of which would have its own typical water consumption values. Hence, the table below was developed to get a general insight on typical water consumption values of the F&B sector and consultation of the reference should be made for more in-depth information.

Table 33: Typical Water Consumption in the Food & Beverage Sector.

Division/Subdivision	Value* (m^3/tonne)	Division/Subdivision	Value* (m^3/tonne)
Reference: [104]			
Animal Feed	0.0 – 4.9	Meat Processing	1.3 – 19.1
Brewing**	2.0 – 30.0	Oilseed and Vegetable Oil	0.1 – 4.4
Dairy	0.2 – 17.2	Olive Oil Processing	2.2 – 10.3
Distillery (Ethanol)	2.9 – 20.6	Soft Drinks & Juices**	1.0 – 51.0
Fish & Shellfish Processing	3.3 – 32.0	Starch Production	0.5 – 13.1
Fruit & Vegetables	0.6 – 15.3	Sugar Manufacturing	0.0 – 1.0
Grain Milling	0.0 – 0.1		

Notes:
* Values reported can be per tonne of raw material or tonne of product; refer citation for more information.
** Values reported in m^3/hl. Author's conversion to m^3/tonne assumes a liquid density of 1000 kg/m^3.

2.1.2. Wastewater Characteristics

Similar to water consumption, F&B wastewater is extremely variable in composition and is dependent on the installation's specifics including operational procedures. Nevertheless, F&B wastewater is generally high in organic content where the levels can be 10 to 100 times those of domestic wastewater [104]. Moreover, divisions that involve the use of salt and brine in processing or preservation (e.g., pickling, fish preservation, and cheesemaking) usually have high chloride content in their wastewater. Typical characteristics of the F&B sector wastewater include [104]:

- Gross and finely suspended solids
- Low and high pH levels
- Free edible fats and oils
- Emulsified material e.g., edible fats and oils
- Soluble biodegradable organic material e.g., BOD
- Dissolved non-biodegradable organics
- Volatile substances e.g., ammonia and organics
- Nutrients e.g., phosphorus and nitrogen compounds
- Pathogens e.g., slaughterhouse and poultry wastewater
- To a lesser extent, pesticide residues not readily degraded during treatment; residues and by-products from the use of chemical disinfection techniques; cleaning products

Table 34 below lists the major contaminants found in the wastewater of the F&B sector including their typical concentrations as retrieved from the literature. Additionally, the identified major contaminants in this section are populated in the table provided in Appendix A for ease of reference.

Table 34: Typical Wastewater Contaminants in the Food & Beverage Sector.

Division / Subdivision	Contaminant (mg/l)					
	FOG	TSS	BOD	COD	TP	TN
Reference: [104]						
Fish Processing	500 – 25,000	---	2,000 – 28,000	2,000 – 60,000	80 – 150	400 – 1,000
Olive Oil Mill	---	65,000 – 120,000	13,000 – 100,000	39,000 – 162,000	---	---
Reference: [105]						
Dairy	200 – 900	600 – 800	1,200	1,800	---	---
Slaughterhouse	1,200	700 – 3,100	1,600 – 2,000	---	---	---
Sugar Mill	5 – 10	250 – 300	1,000 – 1,500	2,000 – 3,000	---	---
Molasses Distillery	---	1,000 – 13,000	7,000 – 95,000	15,000 – 176,000	---	600 – 8,900

Considering the identified major contaminants in Section 2.1.2 and Appendix A, a longlist of applicable wastewater treatment techniques targeting the wastewater contaminants has been developed as given in Appendix B. General water and wastewater related BMP longlist was developed as detailed in Appendix C, which is applicable to all sectors. Section 3 further provides discussion on the applicability of selected advanced wastewater treatment techniques to the F&B sector.

2.2. Pulp and Paper

The Pulp & Paper (P&P) sector is a diverse sector utilizing a range of raw materials to produce a diverse variety of final products. In 2020, the EU-27 had an estimate of 18,242 P&P enterprises employing 606,565 individuals with a total estimated turnover of 178.0 billion Euros [101].

According to NACE Code C Manufacturing Subcode C17, the P&P sector is categorized into 2 divisions and 7 subdivisions [102]. P&P divisions include:

- Manufacture of pulp, paper, and paperboard
- Manufacture of articles of paper and paperboard

2.2.1. Water Consumption

Water consumption in the P&P sector is variable and depends on several factors such as the nature of raw materials and finished products, manufacturing process, equipment, cleaning procedures, facilities capacity for water reuse, among others. The global water consumption of the P&P sector is estimated at 20 BCM per year [106].

In general, water in the P&P sector is consumed in a variety of activities such as [106], [107]:

- Preparation of raw materials and chemicals
- Process water
- Transportation and dilution of pulp
- Equipment and installation cleaning
- Cooling
- Heating (in the form of steam)
- Sealing and lubrication
- Firefighting

Table 35 below lists typical water consumption values for several P&P divisions and subdivisions.

Table 35: Typical Water Consumption in the Pulp & Paper Sector.

Division/Subdivision	Value (m^3/tonne)	Division/Subdivision	Value (m^3/tonne)
Reference: [106]			
Tissue Paper	5 – 30	Newsprint Paper	15 – 30
Printing and Writing Paper	10 – 50	Packaging (virgin & recycled pulps)	6 – 45
Specialty Paper	20 – 80	Corrugated Boards	6 – 40
Reference: [107]			
Sulfite P&P Mill*	43.5 – 65	CTMP*	9.5 – 30
GW Pulp*	5 – 20	Tissue*	9.5 – 50
TMP*	4 – 20	Writing and Printing Paper*	9.5 – 55

Division/Subdivision	Value (m^3/tonne)	Division/Subdivision	Value (m^3/tonne)

Notes:
* Values reported in units of m^3/ADt (air dry tonne of pulp product).

2.2.2. Wastewater Characteristics

Similar to water consumption, P&P wastewater is highly variable in composition and is dependent on the installation's specifics including operational procedures. Nevertheless, P&P wastewater is generally high in organic content. In addition, other contaminants are introduced based on the applied processes during the manufacturing process. For instance, wood preparation wastewater has suspended solids, BOD, dirt, and fibers while the produced wastewater in the digesters house contains resins, fatty acids, color, BOD, COD, AOX, and VOCs [108].

Typical characteristics of the P&P sector wastewater include [107], [108]:

- Low and high pH levels
- Gross and finely suspended solids e.g., TS, TSS
- Soluble biodegradable organic materials e.g., BOD
- Dissolved non-biodegradable organics e.g., phenols
- Volatile organic substances
- Phosphorus and nitrogen compounds
- Adsorbable organically bound halogens (AOX)
- Chelating agents e.g., EDTA
- Chlorates
- Dissolved salts e.g., TDS
- Other physical parameters depending on the applied process such as color and odor

Table 36 below lists the major contaminants found in the wastewater of the P&P sector including their typical concentrations as retrieved from the literature. Additionally, the identified major contaminants in this section are populated in the table provided in Appendix A for ease of reference.

Table 36: Typical Wastewater Contaminants in the Pulp & Paper Sector.

Division / Subdivision	Contaminant (mg/l)						
	pH*	TS	TSS	BOD	COD	TN	Color**
Reference: [108]							
TMP Whitewater	4.6	---	127	1,541	2,713	7	---
TMP	4.2	---	810	2,800	5,600	12	---
CTMP	6.2	---	500	2,500	7,300	---	---
Kraft Mill	8.2	8,260	3,620	---	4,112	350	4,668
Bleach Kraft Mill	10.1	---	37 – 74	128 – 184	1,224 – 1,738	2	---
Sulfite Mill	2.5	---	---	2,000 – 4,000	4,000 – 8,000	---	---

Division / Subdivision	Contaminant (mg/l)						
	pH*	TS	TSS	BOD	COD	TN	Color**
Pulping	10	1,810	256	360	---	---	---
Bleaching	2.5	2,285	216	140	---	---	40
Bleached Pulp Mill	7.5	---	1,133	1,566	2,572	---	4,033
Wood Preparation	---	1,160	600	250	---	---	---
Paper Making	7.8	1,844	760	561	953	11	Black
Newsprint Mill	---	3,750	250	---	3,500	---	1,000
Chip Wash	---	---	6,095	12,000	20,000	86	---
Digester House	11.6	51,583	23,319	13,088	38,588	---	17
Reference: [109]							
Paper Mill***	8.0 – 13.0	350 – 6,300	40 – 1,300	142 – 450	465 – 2,126	---	660 – 3,220

Notes:

* pH value is unitless.

** Units of color are in Platinum-Cobalt scale (Pt-Co).

*** Reference also states AOX: 8.9 – 80.2 mg/l; total phenolic compounds: 294 – 400 mg/l; lignin: 133 – 265 mg/l.

Considering the identified major contaminants in Section 2.2.2 and Appendix A, a longlist of applicable wastewater treatment techniques targeting the wastewater contaminants has been developed as given in Appendix B. General water and wastewater related BMP longlist was developed as detailed in Appendix C, which is applicable to all sectors. Section 3 further provides discussion on the applicability of selected advanced wastewater treatment techniques to the P&P sector.

2.3. Chemicals

The chemicals sector is an extremely diverse sector utilizing a wide range of raw materials to produce a diverse variety of final products. In 2020, the EU-27 had an estimate of 29,872 chemicals enterprises employing 1,212,394 individuals with a total estimated turnover of 739.2 billion Euros [101].

According to NACE Code C Manufacturing Subcodes C19 and C20, the sectors producing chemicals are categorized into 8 divisions and 18 subdivisions [102]. Subcode C21 which is specific to pharmaceutical products was not considered herein as it warrants its own category. The considered chemicals divisions include:

- Manufacture of coke oven products
- Manufacture of refined petroleum products
- Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics, and synthetic rubber in primary forms
- Manufacture of pesticides and other agrochemical products
- Manufacture of paints, varnishes and similar coatings, printing ink and mastics
- Manufacture of soap and detergents, cleaning and polishing preparations, perfumes, and toilet preparations
- Manufacture of other chemical products
- Manufacture of man-made fibers

2.3.1. Water Consumption

Water consumption in the chemicals sector is variable and depends on several factors such as the nature of raw materials and finished products, manufacturing process, equipment, cleaning procedures, facilities capacity for water reuse, among others. In 2019, the global water consumption of the chemicals sector accounted to 3.8 BCM [103].

In general, water in the chemicals sector is consumed in a variety of activities such as [110], [111]:

- Preparation of raw materials and chemicals
- Process water (scrubbing, washing, dust abatement, etc.)
- Equipment and installation cleaning
- Cooling
- Heating (in the form of steam)
- Firefighting

Table 37 below lists typical water consumption values for several chemical divisions and subdivisions.

Table 37: Typical Water Consumption in the Chemicals Sector.

Division/Subdivision	Value* (m^3/tonne)	Division/Subdivision	Value* (m^3/tonne)
<u>Reference</u>: [111]			
Polydimethysiloxane	20	Iron Oxide Pigments	100 – 400
Inorganic Explosives	50 – 500	Chromium (III) Oxide Pigment	60
<u>Reference</u>: [112]			
Phosphoric Acid	4 – 52	NPK Fertilizer	17
<u>Reference</u>: [113]			
Titanium Dioxide (Sulphate Process)	189	Iron Chlorosulphate	320
Soda Ash	2.5 – 3.6	Dicalcium Phosphate	0 – 0.45
<u>Reference</u>: [114]			
Based on 51 European Refineries: 0.1 m^3/t at 5th percentile; 25.5 m^3/t at 95th percentile; Max. 149.7 m^3/t			

Notes:
* Values reported per tonne product.

2.3.2. Wastewater Characteristics

Similar to water consumption, the chemicals sector wastewater is extremely variable in composition and is dependent on the installation's specifics (e.g., raw materials, products being manufactured, manufacturing process, etc.) including operational procedures. Hence, it is challenging to capture all the contaminants expected to be present in the wastewater. In general, the typical characteristics of the chemicals sector wastewater include [110], [111], [112], [113], [114], [115], [116]:

- Extremes in low and high pH levels
- Gross and finely suspended solids e.g., TS, TSS
- Organic compounds e.g., COD, TOC, BOD
- Non-biodegradable organics e.g., POPs, phenols
- Volatile organic substances
- Adsorbable organically bound halogens (AOX)
- Hydrocarbons e.g., benzene, toluene
- Cyanides
- Phosphorus and nitrogen compounds
- Heavy metals e.g., cadmium, chromium, copper, mercury, nickel, lead, zinc, etc.
- Dissolved salts e.g., chloride, fluoride, sulphate, carbonate, etc.
- Color e.g., in pigment manufacturing

Table 38 below lists the major contaminants found in the wastewater of various chemicals sector divisions and subdivisions including their typical concentrations as retrieved from the literature.

Additionally, the identified major contaminants in this section are populated in the table provided in Appendix A for ease of reference.

Table 38: Typical Wastewater Contaminants in the Chemicals Sector.

Division / Subdivision	Contaminant (mg/l)						
	TSS	COD	BOD	Chloride	Heavy Metals	Phenols	Miscellaneous
Reference: [105]							
Refinery, detergent alkylate	121	855	345	1,980	---	160	Oils: 73
Nylon	---	2,000	170	800	---	400	H_2S: 12
Phosphatic Fertilizer Plant	550 – 2,480	---	---	35 – 130	*	---	Fluoride: 3,150 – 4,350
Pesticide DDT	50	3,680	260	11	---	---	Sulphate: 3,840
Pesticide Parathion	---	3,000	700	7,000	---	---	TS: 27,000
Rubber Plant	5,440	10,600	---	---	---	---	TDS: 23,360

Notes:

* (mg/l) Cd: 0.0045 – 0.35; Cr: 0.1 – 0.45; Cu: 0.15 – 0.2; Fe: 3.5 – 5.0; Pb: 0.05 – 0.2; Mn: 0.1 – 0.14; Ni: 0.37 – 0.42.

Considering the identified major contaminants in Section 2.3.2 and Appendix A, a longlist of applicable wastewater treatment techniques targeting the wastewater contaminants has been developed as given in Appendix B. General water and wastewater related BMP longlist was developed as detailed in Appendix C, which is applicable to all sectors. Section 3 further provides discussion on the applicability of selected advanced wastewater treatment techniques to the chemicals sector.

2.4. Textile

The textile sector is a diverse sector utilizing various raw materials to produce a variety of final products. In 2020, the EU-27 had an estimate of 61,011 textile enterprises employing 484,827 individuals with a total estimated turnover of 66.2 billion Euros [101].

According to NACE Code C Manufacturing Subcode C13, the textile sector is categorized into 4 divisions and 10 subdivisions [102]. Textile divisions include:

- Preparation and spinning of textile fibers
- Weaving of textiles
- Finishing of textiles
- Manufacture of other textiles

2.4.1. Water Consumption

Water consumption in the textile sector is variable and depends on several factors such as the nature of raw materials and finished products, manufacturing process, equipment, cleaning procedures, facilities capacity for water reuse, among others. In 2015, the global water consumption of the fashion industry accounted to 79 BCM [117].

In general, water in the textile sector is consumed in a variety of activities such as [118]:

- Preparation of raw materials, chemicals, and dyes
- Process water e.g., for washing, bleaching, dyeing, etc.
- Equipment and installation cleaning
- Cooling and heating
- Firefighting

Table 39 below lists typical water consumption values for several textile divisions and subdivisions.

Table 39: Typical Water Consumption in the Textile Sector.

Division/Subdivision	Value* (m^3/tonne)	Division/Subdivision	Value* (m^3/tonne)
<u>Reference</u>: [118]			
Yarn Dyehouses	17.9 – 52.7	Loose Fiber Dyehouses	28.7 – 53.5
<u>Reference</u>: [119]			
Wool Processing	111	Stock/Yarn Processing	3 – 100
Woven Processing	5 – 114	Non-Woven Processing	3 – 40
Knit Processing	20 – 84	Felted Fabric Finishing	33 – 213
Carpet Processing	8 – 47		

Notes:
* Values reported per tonne product.

2.4.2. Wastewater Characteristics

Similar to water consumption, the textile sector wastewater is highly variable in composition and is dependent on the installation's specifics (e.g., raw materials, products being manufactured, manufacturing process, etc.) including operational procedures. In general, the typical characteristics of the textile sector wastewater include [118]:

- Low and high pH levels
- Gross and finely suspended solids e.g., TS, TSS
- Organic compounds e.g., COD, TOC, BOD
- Non-biodegradable organics e.g., POPs, phenols
- Adsorbable organically bound halogens (AOX)
- Phosphorus and nitrogen compounds
- Heavy metals e.g., chromium, copper, nickel, zinc, antimony etc.
- Dissolved salts
- Color e.g., from dyes
- Natural fiber impurities including biocides and associated material e.g., lignin, sericin, wax, etc.
- Sizing agents e.g., starch, polyacrylates, polyvinyl alcohol, carboxymethylcellulose, etc.
- Preparation agents e.g., mineral oils, ester oils, etc.
- Surfactants e.g., dispersing agents, emulsifiers, detergents, wetting agents, etc.
- Urea
- Complexing agents

Table 40 below lists the major contaminants found in the wastewater of various textile sector processes including their typical concentrations as retrieved from the literature. Additionally, the identified major contaminants in this section are populated in the table provided in Appendix A for ease of reference.

Table 40: Typical Wastewater Contaminants in the Textile Sector.

Process	Contaminant (mg/l)						
	pH*	Color*	TSS	TS	TDS	COD	BOD
Reference: [120]							
Desizing	---	---	---	16,000 – 32,000	---	4,600 – 5,900	1,700 – 5,200
Scouring	10 – 13	694	---	7,600 – 17,400	---	8,000	100 – 2,900
Bleaching	8.5 – 9.6	153	---	2,300 – 14,400	4,800 – 19,500	6,700 – 13,500	100 – 1,700
Mercerizing	5.5 – 9.5	---	---	600 – 1,900	4,300 – 4,600	1,600	50 – 100
Dying	5 – 10	1,450 – 4,750	---	500 – 14,100	50	1,100 – 4,600	10 – 1,800

Process	Contaminant (mg/l)						
	pH*	Color*	TSS	TS	TDS	COD	BOD
Soaping**	12	38	---	---	---	578	---
Burning***	5.0 – 6.5	---	105 – 936	---	---	1,512 – 7,802	675 – 925
Dressing****	7	---	135 – 544	---	---	825 – 1,905	60 – 180

Notes:

* pH values are unitless while color values are in ADMI unit (American Dye Manufacturing Institute)

** Salinity reported as 5,000 mg/l

*** Ammonia reported as 3.0 – 7.9 mg/l

**** Ammonia reported as 5.1 – 14.8 mg/l

Considering the identified major contaminants in Section 2.4.2 and Appendix A, a longlist of applicable wastewater treatment techniques targeting the wastewater contaminants has been developed as given in Appendix B. General water and wastewater related BMP longlist was developed as detailed in Appendix C, which is applicable to all sectors. Section 3 further provides discussion on the applicability of selected advanced wastewater treatment techniques to the textile sector.

2.5. Primary Metals

The primary metals sector is a diverse and fragmented sector utilizing various raw materials to produce a variety of final products. In 2020, the EU-27 had an estimate of 14,423 primary metals enterprises employing 871,475 individuals with a total estimated turnover of 324.2 billion Euros [101].

According to NACE Code C Manufacturing Subcode C24, the primary metals sector is categorized into 5 divisions and 16 subdivisions [102]. Primary metals divisions include:

- Manufacture of basic iron and steel and of ferro-alloys
- Manufacture of tubes, pipes, hollow profiles, and related fittings, of steel
- Manufacture of other products of first processing of steel
- Manufacture of basic precious and other non-ferrous metals
- Casting of metals

2.5.1. Water Consumption

Water consumption in the primary metals sector is highly variable and depends on several factors such as the nature of raw materials and finished products, manufacturing process, equipment, cleaning procedures, facilities capacity for water reuse, among others.

In general, water in the primary metals sector is consumed in a variety of activities such as [121]:

- Preparation of raw materials and chemicals
- Process water e.g., quenching, descaling, dust scrubbing, etc.
- Equipment and installation cleaning
- Cooling and heating
- Firefighting

Table 41 below lists typical water consumption values for several primary metals divisions and processes.

Table 41: Typical Water Consumption in the Primary Metals Sector.

Division/Process	Value* (m^3/tonne)	Division/Process	Value* (m^3/tonne)
__Reference__: [122]			
Hot Rolling	0.1 – 30	Cold Rolling	0.1 – 74
Wire Drawing	0.1 – 6	Continuous Hot Dip Coating	0.1 – 13.9
__Reference__: [121]			
Sinter Plants	0.1 – 0.3	Palletization Plants	0.11 – 1.25
Coke Oven Plants	0.74 – 2.5	Blast Furnaces	0.1 – 3.5
Basic Oxygen Steelmaking Plants	0.8 – 41.7	Electric Arc Furnaces	1 – 42.8

Notes:
* Values reported per tonne product.

2.5.2. Wastewater Characteristics

Similar to water consumption, the primary metals sector wastewater is highly variable in composition and is dependent on the installation's specifics including operational procedures. In general, the typical characteristics of the primary metals sector wastewater include [121], [122], [123]:

- Low and high pH levels
- Gross and finely suspended solids e.g., TS, TSS
- Organic compounds e.g., COD, TOC, BOD
- Volatile organic compounds
- Non-biodegradable organics e.g., POPs, phenols
- Hydrocarbons e.g., benzene, toluene, xylene
- Phosphorus and nitrogen compounds
- Cyanides
- Heavy metals e.g., lead, chromium, copper, nickel, zinc, etc.
- Dissolved salts e.g., fluoride, chloride, sulphate

Table 42 below lists the major contaminants found in the wastewater of various primary metals sector divisions and processes including their typical concentrations as retrieved from the literature. Additionally, the identified major contaminants in this section are populated in the table provided in Appendix A for ease of reference.

Table 42: Typical Wastewater Contaminants in the Primary Metals Sector.

Division/Process	Contaminant (mg/l)						
	Oil	TSS	COD	Heavy Metals	Phenol	Ammonium	Miscellaneous
Reference: [121]							
Coke Oven Plant	40	30 – 40	200 – 6,500	---	500 – 1,500	---	PAH: 0.2
Blast Furnace Gas Scrubbing	---	---	---	*	0.1 – 5	2 – 200	Cyanide: 0.1 – 50
Reference: [123]							
Weak Acid Wastewater	---	200	---	**	---	---	---
Copper Smelter	---	---	---	***	---	---	---

Notes:

* (mg/l) Fe: 6.8; Mn: 0.5; Zn: 0.1 – 29.4; Pb: 0.01 – 5.

** (mg/l) Cu: 2,100; Hg: 15; As: 2,200; Pb: 2,600; Ni: 7; Cd: 110.

*** (mg/l) Cu: 2,000; Zn: 1,000; As: 10,000; Pb: 500; Ni: 1,000; Cd: 500.

Considering the identified major contaminants in Section 2.5.2 and Appendix A, a longlist of applicable wastewater treatment techniques targeting the wastewater contaminants has been developed as given in Appendix B. General water and wastewater related BMP longlist was developed as detailed in Appendix C, which is applicable to all sectors. Section 3 further provides discussion on the applicability of selected advanced wastewater treatment techniques to the primary metals sector.

2.6. Power

The power sector utilizes various types of raw material to produce energy in various forms. In 2020, the EU-27 had an estimate of 166,164 power enterprises employing 1,162,309 individuals with a total estimated turnover of 1,310 billion Euros [101].

According to NACE Code D, the power sector is categorized into 3 divisions and 8 subdivisions [102]. Power divisions include:

- Electric power generation, transmission, and distribution
- Manufacture of gas; distribution of gaseous fuels through mains
- Steam and air conditioning supply

2.6.1. Water Consumption

Water consumption in the power sector is variable and depends on several factors such as the nature of raw materials, the form of energy produced, process involved, equipment, cleaning procedures, facilities capacity for water reuse, among others. Power generation accounts for 10% of the global water withdrawal and 3% of the global water consumption [124].

In general, water in the power sector is utilized in a variety of activities such as [125]:

- Production of process water
- Use of process water e.g., acid washing, flue-gas cleaning, etc.
- Cooling and heating
- Energy generation
- Equipment and installation cleaning
- Sanitary purposes
- Firefighting

Table 43 below lists typical water withdrawal and consumption values for several power sector divisions and subdivisions.

Table 43: Typical Water Withdrawal & Consumption in the Power Sector.

Division/Subdivision	Water Withdrawal (m^3/MWh)	Water Consumption (m^3/MWh)
Reference: [126]		
Coal	78 – 180	0.4 – 1.2
Gas	43.1 – 132.5	0.4 – 1.1
Oil	78 – 180	0.7 – 1.1
Nuclear	107 – 180	0.7 – 1.5
Biopower	132.5	1.1
Concentrated Solar Power	2.9 – 3.4	2.9 – 4.0
Solar Photovoltaic	0.01	0.004
Wind	0.001	---
Hydroelectric	10,000	2.7 – 17.0

2.6.2. Wastewater Characteristics

Similar to water consumption, the power sector wastewater is variable in composition and is dependent on the installation's specifics including operational procedures. In general, the typical characteristics of the power sector wastewater include [125]:

- Gross and finely suspended solids e.g., TS, TSS, dust
- Organic compounds e.g., COD, TOC, BOD
- Non-biodegradable organics e.g., POPs, phenols
- Nitrogen compounds
- Heavy metals e.g., mercury, cadmium, chromium, arsenic, copper, etc.
- Dissolved salts e.g., chloride, fluoride, sulphates, sulfites
- Cyanides
- Hydrocarbons e.g., mineral oils
- Acids and alkalis
- Heat

Table 44 below lists the major contaminants found in the wastewater of various power sector processes including their typical concentrations as retrieved from the literature. Additionally, the identified major contaminants in this section are populated in the table provided in Appendix A for ease of reference.

Table 44: Typical Wastewater Contaminants in the Power Sector.

Division/Process	Contaminant (mg/l)						
	pH*	TSS	TDS	COD	Misc.	Misc.	Misc.
Reference: [127]							
Combined Cycle Power Plant	8.4	1	7,130	166	CO_3^{2-}: 24	HCO_3^-: 98	NO_3^-: 43
Reference: [128]							
Flue Gas Desulfurization Unit**	6 – 7	500	15,000 – 25,000	150	Cl^-: 12,000	SO_4^{2-}: 1,000 – 2,000	NH_4^+: 15 – 30

Notes:

* pH values are unitless.

** (mg/l) F^-: 15; Na^+: 1,500 – 4,500; Ca^{2+}: 1,000 – 2,000; Mg^{2+}: 3,000 – 6,000; Fe: 10 – 20; Cu: 0.5; Hg: 0.05; Cd: 0.1.

Considering the identified major contaminants in Section 2.6.2 and Appendix A, a longlist of applicable wastewater treatment techniques targeting the wastewater contaminants has been developed as given in Appendix B. General water and wastewater related BMP longlist was developed as detailed in Appendix C, which is applicable to all sectors. Section 3 further provides discussion on the applicability of selected advanced wastewater treatment techniques to the power sector.

2.7. Mining

The mining sector is a fragmented sector which involves the extraction of minerals occurring naturally as solids (coal and ores), liquids (petroleum) or gases (natural gas) from the earth. In 2020, the EU-27 had an estimate of 17,052 mining enterprises employing 373,884 individuals with a total estimated turnover of 73.1 billion Euros [101].

According to NACE Code B Mining and Quarrying, the mining sector is categorized into 5 divisions and 15 subdivisions [102]. Mining divisions include:

- Mining of coal and lignite
- Extraction of crude petroleum and natural gas
- Mining of metal ores
- Other mining and quarrying
- Mining support service activities

2.7.1. Water Consumption

Water consumption in the mining sector is variable and depends on several factors such as the type of solid, liquid, or gas to be extracted, extraction process, equipment used, water reuse practices, among others. In 2019, the global water consumption of mining sector accounted to 19 BCM [103].

In general, water in the mining sector is used in a variety of activities such as [129]:

- Transport of extractive waste
- Prevention of extractive waste generation
- Cooling and lubricating drills
- Process water e.g., washing
- Preparation of chemicals
- Dust abatement

Table 45 below lists typical water consumption values for several mining divisions and subdivisions.

Table 45: Typical Water Consumption in the Mining Sector.

Division/Subdivision	Value* (m^3/tonne)	Division/Subdivision	Value* (m^3/tonne)
__Reference__: [130]			
Bauxite	0.4	Molybdenum	240.9
Cobalt	208.4	Silver	1,713
Copper	43.2	Uranium	2,746
Iron Ore	1.4	Zinc	11.9
Lead	6.6	Gold	265,861
Manganese	1.4	Nickel	193.8
Palladium	210,713	Platinum	313,496

Notes: * Values reported per tonne product.

2.7.2. Wastewater Characteristics

The majority of polluted wastewater in mining is not produced from process water, but from the run-off and infiltration of rainwater. When passing through mines and tailing pits, rainwater accumulates mineral impurities and can also trigger acidification reactions. As so-called (acidic) seepage water, it represents the most problematic and volume-wise largest wastewater flow in mining [129]. In general, the typical characteristics of the mining sector wastewater include [129]:

- Extremes in low and high pH levels
- Gross and finely suspended solids e.g., TS, TSS
- Organic compounds e.g., COD, TOC
- Nitrogen and phosphorus compounds
- Various heavy metals
- Naturally occurring radioactive materials e.g., uranium, radium
- Dissolved salts e.g., chloride, sulphate
- Oils and hydrocarbons

Table 46 below lists the major contaminants found in the wastewater of various mining sector divisions and processes including their typical concentrations as retrieved from the literature. Additionally, the identified major contaminants in this section are populated in the table provided in Appendix A for ease of reference.

Table 46: Typical Wastewater Contaminants in the Mining Sector.

Process	Contaminant (mg/l)						
	pH*	Conductivity*	TSS	Heavy Metals	Misc.	Misc.	Misc.
Reference: [131]							
Gold Mining	7.1 – 8.6	94 – 979	---	**	Mg: 31 – 1,488	Li: 0.2 – 2.8	K: 4.7 – 114
Zinc and Lead Mining	8.23	---	2,495	***	---	---	---
Zinc-rich Acid Mine Drainage	3.6	191.5	---	****	Mg: 19	Ca: 136	Al: 12.2

Notes:

* pH values are unitless while conductivity values are in mS/m

** (mg/l) As: 0.04; Sb: 35 – 160; Ni: 0.04 – 0.07; Fe: 0.07 – 0.11; Mn: 0.42 – 1.3.

*** (mg/l) As: 0.08 – 0.02; Zn: 14.5; Pb: 11.5; Cd: 0.05.

**** (mg/l) Zn: 552; Mn: 17.

Considering the identified major contaminants in Section 2.7.2 and Appendix A, a longlist of applicable wastewater treatment techniques targeting the wastewater contaminants has been developed as given in Appendix B. General water and wastewater related BMP longlist was developed as detailed in Appendix C, which is applicable to all sectors. Section 3 further provides discussion on the applicability of selected advanced wastewater treatment techniques to the mining sector.

3. Advanced Wastewater Treatment Techniques

The following section has been specifically developed to address ENVITECC's commitment to the depollution of the Mediterranean Sea from the discharge of untreated wastewater. The identified advanced wastewater treatment techniques are intended to serve as a crucial polishing step in wastewater treatment schemes, enabling the implementation of water reuse initiatives. They are also designed to effectively remove a wide range of contaminants from effluents including persistent organic pollutants (POPs). Additionally, these advanced wastewater treatment techniques facilitate the recovery of valuable compounds, further promoting sustainable resource management. The advanced wastewater treatment techniques covered include activated carbon, ion exchange, nanofiltration and reverse osmosis.

Table 47 below summarizes the shortlisted advanced treatment techniques that were considered in the development of the wastewater technology guide for the F&B, P&P, chemicals, textile, primary metals, power, mining, and real estate sectors.

Table 47: Advanced Treatment Techniques for the Investigated Sectors.

Technique	Description	Target Pollutants	Objective
Adsorption by Activated Carbon	Uses the physical adsorption process to remove soluble contaminants from wastewater. GAC and PAC are highly effective adsorbents due to their large surface area and high porosity.	Various Non-Biodegradable Organic Substances Heavy Metals	Water Conservation Reduction of Wastewater Emissions Wastewater Treatment Water Reuse Resource Recovery
Ion Exchange	Ion exchange is a physical-chemical process in which ions are swapped between a solution phase and a solid resin phase. Different resins are used to target different charged particles.	Monovalent & Divalent Ions Heavy Metals	
Nanofiltration	A membrane filtration method used to remove particles as small as 1 nm from wastewater. This includes divalent and large monovalent ions (e.g., heavy metals).	Monovalent & Divalent Ions Heavy Metals Organics POPs and many others	
Reverse Osmosis	A membrane filtration method used to remove small ions from water. Requires a high-pressure hydraulic pressure gradient to counteract the osmotic pressure gradient that would otherwise favor movement of water into (instead of out of) the concentrated wastewater.	Monovalent & Divalent Ions Heavy Metals Organics POPs and many others	

3.1. Adsorption by Activated Carbon

Adsorption is the transfer of soluble substances from the wastewater phase to the surface of highly porous solid particles referred to as adsorbents. The adsorbent has a finite capacity for each compound to be removed. Hence, when this capacity is exhausted, the adsorbent is spent and has to be replaced by fresh material. The spent adsorbent either has to be regenerated or incinerated. Potential adsorbents for adsorptive wastewater purification are activated carbon (granular and powder form), lignite coke, aluminum oxide, zeolites and adsorber resins [118]. For the purpose of this section, activated carbon is considered.

The utilization of adsorption by activated carbon offers a versatile solution in a range of applications including air and wastewater treatment, water reuse initiatives, metal recovery and purification processes.

Activated carbon adsorption is applied to remove organic contaminants, mainly those with refractory, toxic, colored, odorous, and residual amounts of inorganic contaminants such as nitrogen compounds, sulphides, and heavy metals [110].

Environmental Performance and Operational Data

According to various bench, pilot and full-scale studies as outlined in the EPA Drinking Water Treatability Database [132], activated carbon has proven to be effective in the reduction of various organic compounds and heavy metals as summarized in Table 48 below. It should be noted that the removal efficiencies are highly dependent on the nature of the wastewater, the type of activated carbon, contact time, and bed depth.

Table 48: Activated Carbon Key Performance Indicators.

Contaminant / KPI	Removal Efficiency [132]	Contaminant / KPI	Removal Efficiency [132]
1,2-Dibromoethane	99%	Dicrotophos	89%
17a-ethynyl estradiol	99%	Mercury	95 – 99%
4-Nonylphenol	Up to 100%	Methomyl	98%
Acetochlor	59 – 63%	Methyl tert-butyl ether	95%
Alachlor	Up to 100%	Mevinphos	95 – 99%
Aldicarb	97%	TOC	20 – 60%
Arsenic	11 – 99%	DOC	8 – 77%
Benzene	99%	Oxamyl	85 – 95%
Carbofuran	86 – 100%	Per-and-Polyfluoroalkyl Substances	56 – 99%
Chlortetracycline	80 – 85%	Perchlorate	Up to 100%
Chromium (VI)	Up to 100%	Perfluorooctane Sulfonate	Variable but can be highly effective
Cis-1,2-dichloroethylene	78 – 99%	Perfluorooctanoic Acid	Variable but can be highly effective
Cobalt	Up to 99%	Strychnine	77 – 86%
Cyclonite (RDX)	70 – 90%	Tetrachloroethylene	Up to 100%
Dichlorvos	96 – 99%	Trichloroethylene	75 – 99%

When the adsorptive capacity of the adsorbent has been exhausted, it must be replaced and subsequently regenerated. This process entails the use of thermal energy to heat the adsorbents up to temperatures of 750 – 1000 °C. Moreover, the regeneration process of Granular Activated Carbon (GAC) releases off-gases that contain thermal and chemical decomposition products of the adsorbed compounds which would require additional waste gas treatment. If the GAC cannot be regenerated, it has to be disposed of as chemical waste and incinerated [110].

Sector-Specific Applications

Table 49 below lists several examples of sector specific applications for the use of activated carbon. In addition, it includes various contaminants that activated carbon is able to effectively target and remove as retrieved from the literature and/or advertised by technology providers.

Table 49: Activated Carbon Sector Specific Applications.

Sector	Applications
Food & Beverage	
General:	• Removal of color, taste, and odor as well as organic contaminants from F&B wastewater [133].
Specific:	• Sweetener purification (cane sugar, glucose, and syrups). Removes off-flavors such as 2-aminoacetophenone, colored impurities, and color precursors (hydroxymethylfurfural) [134]. • Purification of fruit juices and alcoholic drinks. Removes organoleptic discrepancies (color and odor) in wines, mycotoxin patulin from apple juice, mycotoxin ochratoxin A from wine and juices, traces of pesticides, and taste and color from beer [134]. • Removes tannins and other impurities in the wine growing industry [133]. • Purification of carbon dioxide gas produced in breweries prior to its re-use in food grade applications. Removes taste and odor compounds such as hydrogen sulphide, dimethyl sulphide, mercaptans and other organics [133], [134]. • Decaffeination of beverages [135]. • Production of high purity beverage water. Removes feedwater impurities such as humic substances, taste and odor compounds (geosmin and 2-methylisoborneol), pesticides, disinfectants (chlorine, chloramine and ozone), and disinfection by-products (trihalomethanes) [134]. • Purification of edible oils. Removes polycyclic aromatic hydrocarbons (PAH) from edible oils and fats, and polychlorinated biphenyl and dioxins from fish oils [134].
Pulp & Paper	
General:	• Reduction of TOC, COD, DOC, AOX, turbidity, color and odor from P&P wastewater [136], [137], [138].
Specific:	• Removal of color from P&P wastewater that is mainly due to the presence of chromophoric compounds from wood extractives, lignin derivatives and organochlorine compounds [139].
Chemicals	
General:	• Removal of organics (TOC, COD), BTEX (benzene, toluene, ethylbenzene and xylene), phenols, colors, AOX, pesticides, surfactants, chlorinated hydrocarbons, and heavy metals from chemicals sector wastewater [140], [141] [142].
Specific:	• Treatment of oil refinery wastewater. Includes the treatment of condensate water for reuse (removal of TOC), wastewater treatment (removal of hydrogen sulphide and organic chemicals), removal of VOC and SVOC from off-gas and vent gas (benzene) [143]. • Treatment and purification of oleo chemicals. Deodorization and decolorization of glycerin products [144].

Sector	Applications
	• Treatment of organic chemicals. Purification of amino acids and organic acids [144]. • Production and purification of agro chemicals [144]. • Production of phosphoric acid (removes humic acids), hydrochloric acid (removes chlorobenzene), amine purification (removes organic compounds) [142].
Textile	
General:	• Removal of TOC, COD, color, AOX in dyestuffs, and organophosphorus flame retardants from textile industry wastewater [118].
Specific:	• Removal of aromatic solvents (benzene, toluene, xylene), chlorinated aromatics (chlorobenzene), phenolics, cationic, mordant, and acid dyes, reactive, dispersed, basic and sulphur dyes, and surfactants (alkyl benzene sulfonates) [145]. • Removal of heavy metals from textile wastewater (Zn, Cr, Cd) [146].
Primary Metals	
General:	• Removal of heavy metals such as mercury and treatment of off-gas streams containing combustion emissions and POPs from primary metals wastewater [123]. • Reduction of organic contaminants such as COD from steel manufacturing wastewater [147].
Specific:	• Removal of dioxins and mercury from the flue gases of sintering processes in steel manufacturing plants [148].
Power	
Specific:	• Removal of mercury from flue gas generated by coal powered power plants [149]. • Treatment of boiler feed water for the removal of various contaminants [150].
Mining	
General:	• Removal of cyanide, heavy metals (arsenic, lead, copper, cadmium, mercury), and organic compounds (phenols, solvents) [151].
Specific:	• Recovery of gold and other precious metals from cyanide leach solutions [152], [153].
Real Estate	
Specific:	• Swimming pool water. Adsorption of chloramines, disinfection byproducts, and chlorine-nitrogen compounds that are irritating to swimmers (eyes, nose, breathing), and help meet regulatory standards for potentially harmful contaminants [154]. • Municipal wastewater treatment. Removal of pathogens, oxygen demanding compounds, and inorganic and synthetic organic chemicals [154]. • Potable water purification. Removal of natural and synthetic organic pollutants and suspended solids from surface and groundwater sources, in addition to potentially harmful disinfection byproducts, and residual oxidizing agents (chlorine) formed during potable water treatment processes [154]. • Residential point of use and entry water treatment. Improvement of taste and odor, reduction of chlorine, removal of catalytic chloramine, reduction of bacterial growth by bacteriostatic properties, and removal of PFAS [155], [156].

Economics

The CAPEX of activated carbon is dependent on the system's configuration, capacity, material of construction, type and specifications of the activated carbon, among other factors. Indicative CAPEX:

- For GAC: 0.3 – 0.5 Euros per m^3 for up to 1,000 m^3/day design capacity [110].
- For Powdered Activated Carbon (PAC): 150,000 Euros for an automatic dosing installation [110].

OPEX includes the costs associated with the regeneration of the activated carbon, whether done onsite or offsite by a specialized company. When the activated carbon can no longer be generated, new activated carbon must be purchased. Indicative OPEX:

- For GAC: Less than 0.5 Euros per m^3 for more than 1,000 m^3/day design capacity and without taking into consideration the costs associated with regeneration [110].

Real Scale Implementation Examples

Below are real scale implementation examples as retrieved from the literature:

- Example 1 [157]: Full-scale implementation at a chemical crop protection products facility.

  A factory producing chemical crop protection products needed to reduce AOX levels and pesticide residues in its wastewater to very low legal levels before it could be transported to a nearby treatment plant. Rather than store the contaminated water in giant tanks on site until it could be sent for specialist disposal, a process that is both costly and inconvenient, the manufacturers sought a more efficient solution. The wastewater is characterized with fluctuating concentrations of chlorinated, fluorinated, and brominated AOX components. The installed activated carbon system was able to treat peak AOX of 300 mg/l, reducing them to the legal limit of 0.2 µg/l. The installed unit has a flowrate of 2 m^3/h.
- Example 2 [158]:Full-scale implementation at Sweeney Water Treatment Plant for the treatment of river water contaminated by PFAS.

  GAC filters are installed at Sweeney Water Treatment Plant as of October 2022. These filters are highly effective at treating drinking water, removing PFAS to at or near non-detectable levels. The PFAS found in the Cape Fear rivers result largely from decades of releases by the chemical plants of Chemours and DuPont.
- Example 3: Full-scale implementation at various installations investigated under the primary metals BREFs.

  Activated carbon was reportedly used in several processes including treatment of wastewater from galvanizing line [122], treatment of wastewater contaminated with oil and grease [122], reduction of polychlorinated dibenzo-p-dioxins and dibenzofurans ahead of electrostatic precipitators in the treatment of emissions to air [121], used in the regenerative activated carbon process for desulphurisation and NOx abatement [121], removal of mercury from primary smelters [123], and removal of VOC and mercury from off-gas of various gaseous streams [123].

Technology Providers

Table 50 below lists various technology providers for activated carbon systems and activated carbon adsorbents in ENVITECC countries:

Table 50: Activated Carbon Technology Providers.

Product Type	Country	Technology Provider	Technology Provider Website
With Offices in Europe and/or Middle East and North Africa (MENA) Region			
Activated Carbon	Europe	Carbotech	Link
Activated Carbon	Europe	Chemviron	Link
Activated Carbon	Europe	Desotec	Link
Activated Carbon	Europe	Donau Carbon	Link
Activated Carbon	Europe/MENA	Jacobi Group	Link

Product Type	Country	Technology Provider	Technology Provider Website
Activated Carbon	Europe/MENA	Norit	Link
Local Suppliers in ENVITECC Countries			
AC System	Albania	European Water Technologies	Link
AC System	Albania	Albuji	Link
AC System	Bosnia and Herzegovina	Nobilis	Link
AC System	Egypt	Mid Water	Link
AC System	Egypt	Water Tech	Link
AC System	Lebanon	Water Frame	Link
AC System	Lebanon	PWP	Link
AC System	Lebanon	Anhar	Link
AC System	Montenegro	Nobel	Link
AC System	Morocco	Casa Merchants	Link
AC System	Morocco	Geissmann	Link
AC System	Tunisia	Hydropro	Link
AC System	Türkiye	Aquamatch	Link
AC System	Türkiye	Teknik Aritma	Link
AC System	Türkiye	Angstrom	Link
Activated Carbon	Albania	Albania Distribution Chemicals	Link
Activated Carbon	Bosnia and Herzegovina	Nobel	Link
Activated Carbon	Lebanon	RN Chemicals	Link
Activated Carbon	Morocco	Prochimag	Link
Activated Carbon	Morocco	Monde De L'Eau	Link
Activated Carbon	Tunisia	ThermEco	Link

3.2. Ion Exchange

Ion exchange is the removal of undesired or hazardous ionic constituents from wastewater and their replacement by more acceptable ions from an ion exchange resin, where they are temporarily retained and afterwards released into a regeneration or backwashing liquid [125].

The equipment of an ion exchanger usually consists of [125]:

- A vertical cylindrical pressure vessel with corrosion-resistant linings that contains the resin, usually as a packed column with several possible configurations
- A control valve and piping system directing the flows of wastewater and regeneration solution to their proper locations
- A system to regenerate the resin consisting of salt-dissolving and dilution control equipment

Ion exchangers commonly in use are macroporous granule resins with cationic or anionic functional groups, such as [110]:

- Strong acid cation exchangers, neutralizing strong bases and converting neutral salts into their corresponding acids
- Weak acid cation exchangers, able to neutralize strong bases and used for dealkalization

- Strong base anion exchangers, neutralizing strong acids and converting neutral salts into their corresponding bases
- Weak base anion exchangers, neutralizing strong acids and used for partial demineralization

The ion exchange operation cycle is comprised of [110]:

- The actual ion exchange operation
- The backwash stage, including removal of accumulated particles and reclassification of the ion exchange resin bed
- The regeneration stage, using a low volume/high concentration solution, reloading the ion exchange resin with the respective ion and releasing the unwanted ion species to the regeneration solution
- The displacement, or rinse with a slow water flow, of the regeneration solution through the bed
- The fast rinse, removing the remaining traces of the regeneration solution, including any residual hardness, from the resin bed.

The utilization of ion exchange offers a versatile solution in a range of applications including wastewater treatment, water reuse initiatives, compound recovery and purification/concentration processes.

Ion exchange is effective in reducing ion content in wastewater including metals and some ionic organics [125].

Environmental Performance and Operational Data

According to various bench and pilot-scale studies as outlined in the EPA Drinking Water Treatability Database [132], ion exchange has proven to be effective in the reduction of various heavy metals and organic compounds as summarized in Table 51. It should be noted that the removal efficiencies are highly dependent on the nature of the wastewater, contamination level, type of resin, and presence of competing species, among other factors.

Table 51: Ion Exchange Key Performance Indicators.

Contaminant / KPI	Removal Efficiency [132]	Contaminant / KPI	Removal Efficiency [132]
Arsenic	99%	Mercury	90%
Chlortetracycline	65 – 95%	DOC	32 – 86%
Chromium	68 – 100%	TOC	41 – 68%
Cobalt	99%	Per-and-Polyfluoroalkyl Substances	55 – 99%
Cyanide	99%	Perfluorooctane Sulfonate	90 – 99%
Fluoride	75 – 100%	Perchlorate	90 – 99%
Perfluorooctanoic Acid	99%	Radium	62 – 99%
Strontium	99%	Uranium	99%

The regeneration of ion exchange resins results in a small volume of concentrated acid or salt solution, which contains the removed ions originating from the resin. This enriched liquid has to be treated separately to remove these ions, e.g., heavy metals by precipitation [110].

The rinsing water from regeneration contains the same ions as the brine, but in relatively low concentrations. Whether this part can be discharged directly or has to undergo treatment depends on the actual concentrations. At a plant in Germany, the rinsing water from regeneration is reused in waste gas scrubbers [110].

Ion exchange implies the consumption of ion exchange resins, regeneration liquids, water for backwashing and rinsing, and energy for the pumps. The addition of other chemicals e.g., to suppress microbiological fouling may be necessary [110].

Sector-Specific Applications

Table 52 below lists several examples of sector specific applications for the use of ion exchange. In addition, it includes various contaminants that ion exchange is able to effectively target and remove as retrieved from the literature and/or advertised by technology providers.

Table 52: Ion Exchange Sector Specific Applications.

Sector	Applications
Food & Beverage	
General:	• Used for water softening (removal of Mg, Ca), demineralization (removal of cationic and anionic ions), dealkalization (removal of alkalinity), odor and color removal, removal of various organic contaminants (NOM, TOC) from F&B wastewater [159].
Specific:	• Corn and starch deashing and polishing (removal of unwanted contaminants and ions), chromatographic separation, decolorization (removal of unwanted flavors, aromas, as well as color precursors such as hydroxymethylfurfural [160]. • Production of healthy carbohydrates (fractionation of oligosaccharides), purification and separation of sugar alcohols [160]. • Cane sugar decolorization, liquid sugar production (removal of minerals, color, and impurities) [160]. • Beet sugar softening and chromatographic separation [160]. • Demineralization, decationization, deashing, and chromatographic separation of dairy products such as whey and lactose [161].
Pulp & Paper	
General:	• Used for water softening (removal of Mg, Ca), demineralization (removal of cationic and anionic ions), dealkalization (removal of alkalinity), odor and color removal, removal of various organic contaminants (NOM, TOC) from P&P wastewater [159].
Specific:	• Treatment of process water (removal of iron, ammonium, calcium and magnesium salts, removal of organic compounds such as humic acids which can compete with brightening agents [162]. • Treatment of hood condensate which is produced when drying paper. This polished water can be reused in the process [162]. • Treatment of boiler feed water and boiler condensate polishing [162]. • Removal of chloride and potassium in Kraft Mill process water [163]. • Recovery of sulfuric acid from chlorine dioxide generators used in pulp bleaching [163].
Chemicals	
General:	• Used for water softening (removal of Mg, Ca), demineralization (removal of cationic and anionic ions), dealkalization (removal of alkalinity), removal of heavy metals,

Sector	Applications
	odor and color removal, removal of various organic contaminants (NOM, TOC) from chemical industry wastewater [159].
Specific:	• Removal of divalent ions during the production of chlorine and caustic soda [164]. • Removal of sulfuric acid and organic acids from streams during phenol production [164]. • Used as a catalyst in the production of petrochemicals [164]. • Removal and recovery of various heavy metals [164]. • Purification of brine during chloralkali production [165]. • Adsorption of carbon dioxide from air or from flue or exhaust gases [165].
Textile	
General:	• Used for water softening (removal of Mg, Ca), demineralization (removal of cationic and anionic ions), dealkalization (removal of alkalinity), removal of heavy metals, color removal, removal of various organic contaminants (NOM, TOC) from textile industry wastewater [159].
Specific:	• Removal of dyes such as Acid Orange 10, Disperse Violet 28, etc. [166], [167]. • Removal and recovery of heavy metals (chromium, nickel, copper, zinc) [168], [169], [170].
Primary Metals	
General:	• Used for water softening (removal of Mg, Ca), demineralization (removal of cationic and anionic ions), dealkalization (removal of alkalinity), removal of heavy metals, removal of various organic contaminants (NOM, TOC) from primary metals wastewater [159].
Specific:	• Isolation and extraction of heavy metals (nickel, copper, cobalt, zinc) [171]. • Treatment and purification of pickling bath water [172].
Power	
General:	• Used for water softening (removal of Mg, Ca), demineralization (removal of cationic and anionic ions), dealkalization (removal of alkalinity), removal of heavy metals, removal of various organic contaminants (NOM, TOC) from power industry wastewater [159].
Specific:	• Removal of radioactive materials from contaminated water in nuclear power plants [173]. • Steam generator blowdown. Purifies water removed from the plant's steam cycle [173]. • Softening and demineralization of boiler feed water in steam generated power plants [174]. • Removal of heavy metals and metal oxides from condensate streams [174].
Mining	
General:	• Used for water softening (removal of Mg, Ca), demineralization (removal of cationic and anionic ions), dealkalization (removal of alkalinity), removal of heavy metals, removal of various organic contaminants (NOM, TOC) from mining wastewater [159].
Specific:	• Isolation and extraction of various heavy metals. Specific resin types are selective to specific metals [171], [175]. • Gold recovery [171]. • Recovery of uranium from sulfuric acid leach systems [176]. • Treatment of wastewater streams like acid mine drainage and tailings (removal of toxic heavy metals, and harmful anions such as selenate and sulphate) [177].
Real Estate	
General:	• Used for water softening (removal of Mg, Ca), demineralization (removal of cationic and anionic ions), dealkalization (removal of alkalinity), odor, taste and color removal, removal of various organic contaminants (NOM, TOC) from real estate water and wastewater [159].
Specific:	• Removal of disinfection byproducts and trihalomethane [178], [179]. • Water softening to reduce scale formation in plumbing [178].

Sector	Applications
	• Removal of toxic heavy metals (arsenic, chromium, lead, mercury) [178], [179].. • Removal of boron, sulphate, nitrate, perchlorate, PFAS [178], [179].

Economics

The CAPEX of an ion exchange system is highly variable and depends on the systems configuration, design capacity, material of construction, feed wastewater quality, choice of resin, among other factors. Indicative CAPEX is 800,000 Euros per 1 m^3/min design capacity [129].

OPEX includes energy and chemical consumption in addition to resin replacement when exhausted. Indicative OPEX is 0.2 – 0.5 Euros per m^3 [129].

Real Scale Implementation Examples

Below are some real scale implementation examples:

- Example 1 [180]: Full-scale implementation in the treatment of groundwater to address PFAS contamination in a former fire training area at an Australian air base.

  Installation of a regenerable IX treatment system capable of treating up to 12.6 L/s of PFAS-contaminated groundwater. Average influent PFAS concentration is 30.8 µg/L with 29.1 µg/L being PFOS and PFHxS. Two parallel trains of lead-lag SORBIX RePURE IX resin vessels for PFAS removal were employed followed by two parallel trains of lead-lag SORBIX PURE polish IX resin vessels to enhance short-chain PFAS removal. The treated water quality from the treatment system has been consistently below the standard level of detection for PFHxS and PFOS, readily achieving compliance with the 0.07 µg/L HBGV target.
- Example 2 [181]: Full-scale implementation in the treatment of flue gas desulfurization wastewater.

  The motivation of the project is to achieve zero liquid discharge. Treatment system consists of lime/soda chemical softening to remove the majority of hardness, weak acid cation ion exchange to remove residual hardness, two passes of RO to pre-concentrate the brine, followed by forward osmosis and finally evaporation and crystallization. Permeate from the forward osmosis system is recycled to the two-pass RO system. Water is completely consumed by the evaporation/crystallization system.
- Example 3 [125]: Real-scale implementation in various power plants as described by the BREF.

  Ion exchange resins are used for the treatment of boiler feed water.

Technology Providers

With regards to ion exchange systems, the complete system is made of several components such as pumps, vessels, various instrumentations, and control systems in addition to the use of various chemicals and resins. Herein, technology providers for complete ion exchange skids and ion exchange resins in ENVITECC countries are provided as listed in Table 53.

Table 53: Ion Exchange Technology Providers.

Product Type	Country	Technology Provider	Technology Provider Website
With Offices in Europe and/or MENA Region			
Ion Exchange Resin	Europe/MENA	Dupont	Link
Ion Exchange Resin	Europe	Evoqua	Link
Ion Exchange Resin	Europe/MENA	Jacobi	Link
Ion Exchange Resin	Europe	Koch Separation Solutions	Link
Ion Exchange Resin	Europe/MENA	Lanxess	Link
Ion Exchange Resin	Europe/MENA	Purolite	Link
Local Suppliers in ENVITECC Countries			
Ion Exchange System	Albania	Albuji	Link
Ion Exchange System	Albania	EWT	Link
Ion Exchange System	Bosnia and Herzegovina	Adepto	Link
Ion Exchange System	Bosnia and Herzegovina	Nobel	Link
Ion Exchange System	Bosnia and Herzegovina	Nobilis	Link
Ion Exchange System	Egypt	Mid Water	Link
Ion Exchange Resin	Egypt	Water Tech	Link
Ion Exchange Resin	Egypt	Dar El Meyah	Link
Ion Exchange System	Lebanon	Water Frame	Link
Ion Exchange System	Lebanon	PWP	Link
Ion Exchange System	Lebanon	Anhar	Link
Ion Exchange System	Montenegro	Nobel	Link
Ion Exchange Resin	Montenegro	Una	Link
Ion Exchange System	Morocco	Casa Merchants	Link
Ion Exchange Resin	Morocco	Geissmann	Link
Ion Exchange Resin	Morocco	Monde De L’Eau	Link
Ion Exchange System	Tunisia	Ideale Eau	Link
Ion Exchange System	Tunisia	ETE	Link
Ion Exchange System	Tunisia	ThermEco	Link
Ion Exchange System	Türkiye	Vatek	Link
Ion Exchange System	Türkiye	Angstrom	Link
Ion Exchange System	Türkiye	Aquamatch	Link

3.3. Nanofiltration

A membrane process involves the permeation of a liquid through a semi-permeable membrane resulting in two segregated streams which are the permeate stream and the concentrate stream. The driving force for this process is the pressure difference across the membrane. Compared to reverse osmosis, the operating pressure of nanofiltration is lower.

Nanofiltration membranes have larger pore size compared to reverse osmosis which is in the range of 0.001 – 0.01 microns. Nanofiltration membranes allow water, single valence ions (e.g., fluorides, sodium, and potassium chloride) and nitrates to pass through, while retaining multiple valence ions (e.g., sulphate and phosphates). In addition, large organic compounds can be retained by nanofiltration membranes [110].

Membranes are available in various materials and configurations. The optimum system for a particular application will depend on the nature of the wastewater since different materials have varying resistances to dissolved substances. For example, the polyamide-based membranes are normally superior to cellulose acetate-based membranes for the removal of trace organic molecules [110].

Even under the best pretreatment installations, membranes will foul and deteriorate in performance if cleaning is not ensured. Hence, membrane systems should be designed in such a way that those modules can be taken offline and cleaned chemically or mechanically [110].

Industrial membrane plants usually consist of three separate sections [110]:

- Pre-treatment section where the feed is treated by clarification and subsequent filtration. Filtration can be achieved in stages with decreasing pore size
- Membrane section where high-pressure is applied and wastewater flows across the membrane
- Post-treatment section where the permeate is prepared for reuse or discharge while the concentrate stream is collected for further processing or disposal

Membrane units are arranged as modules either in parallel to provide the necessary hydraulic capacity or in series to increase the degree of efficiency.

The utilization of NF systems offers a versatile solution in a range of applications including wastewater treatment, water reuse initiatives, compound recovery and purification/concentration processes.

NF systems are used to remove numerous types of contaminants which can include monovalent and divalent ions, heavy metals, pathogens, and organic compounds including toxic or inhibitory substances such as POPs [110].

Environmental Performance and Operational Data

Table 54 below summarizes key performance indicators for NF systems based on data retrieved from the literature. It should be emphasized that the ultimate performance of an NF system is highly dependent on the nature and characteristics of the incoming wastewater, type of membrane, operational procedures (antiscalant regimes, cleaning schedules, etc.), among others.

Table 54: Nanofiltration Key Performance Indicators.

Contaminant / KPI	Removal/Rejection Efficiency	Contaminant / KPI	Removal/Rejection Efficiency
Reference: [132]			
17a-ethynyl estradiol	24 – 99%	Natural Organic Matter	83 – 95%
4-Nonylphenol	100%	Per- and Polyfluoroalkyl Substances	42 – 99%
Alachlor	up to 100%	Perchlorate	18 – 92%
Arsenic (V)	62 – 100%	Perfluorooctane Sulfonate	55 – 99%
Cryptosporidium	> 6-log	Perfluorooctanoic Acid	80 – 100%
Cyanide	88%	Simazine and Simazine Degradates	42 – 95%
Diuron	3 – 92%	Strontium	65 – 100%
Ibuprofen	92 – 99%	Trichloroethylene	81 – 98%
Methyl tert-butyl ether	97%	Uranium	13 – 99%
Microcystins	94 – 99%		
Reference: [110]			
Atrazine	> 70%	Perchlorethene	90 – 92%
Cadmium compounds	> 90%	Tetrachloromethane	96%
Ethylene dichloride	71 %	TOC	80 – 90%
Inorganic mercury	> 90%	Trichlorobenzene	96%
Organic mercury	> 90%		
Reference: [129]			
Aluminum	> 95 %	Nickel	> 95 %
Arsenic (V)	> 90 %	Lead	> 84 %
Copper	> 90 %	Selenium	> 90 %
Iron	> 95 %	Zinc	> 95 %
Manganese	> 95 %		

Membrane treatment produces a waste stream (concentrate), in which the target substances are present at much higher levels than their concentration in the feed wastewater. An assessment needs to be made as to whether this residue can be recycled, disposed of, or needs further treatment. With organic substances, the concentration increase might improve the conditions for subsequent oxidative destruction processes. With inorganic substances, the concentration stage could be used as part of a recovery process. In both cases, the permeate water from a membrane process could potentially be reused or recycled in the industrial process, thus reducing water input and discharge [110].

NF systems consume energy and chemicals. Energy consumption is directly related to the flowrate and pressure requirements while chemical consumption is dependent on the tendency for fouling and frequency of chemical cleaning [110].

Sector-Specific Applications

Table 55 below lists several examples of sector specific applications for the use of nanofiltration. In addition, it includes various contaminants that nanofiltration is able to effectively target and remove as retrieved from the literature and/or advertised by technology providers.

Table 55: Nanofiltration Sector Specific Applications.

Sector	Applications
Food & Beverage	
General:	Removal of divalent and multivalent ions (Ca, Mg, bicarbonate, phosphate, sulphate), removal of organic compounds (NOM, COD, TOC, DOC), pesticides, pathogens and color, and reduction of TDS from F&B wastewater [182], [183].
Specific:	Treatment of effluents for the purpose of water reuse [161].
	Dewatering and desalting of lactose and whey [161].
	Starch sweeteners and sugar concentration and desalting [184].
	Beverage dealcoholizing/alcohol adjustment, tartaric acid removal from wines, reduction of volatile acids in wines [184].
	Concentration of dairy products [182].
	Grape juice concentration for wine processing [182].
	Protein, peptide, and hydrolysate separation [185].
Pulp & Paper	
General:	Removal of divalent and multivalent ions (Ca, Mg, bicarbonate, sulphate), removal of organic compounds (NOM, COD, TOC, DOC, AOX), and color, and reduction of TDS from P&P wastewater [182], [183].
Specific:	Treatment of effluents for the purpose of water reuse [161].
	Caustic recovery, purification, and reuse [186].
	Treatment and recycle of whitewater [163].
Chemicals	
General:	Removal of divalent and multivalent ions (Ca, Mg, bicarbonate, sulphate, phosphate, heavy metals), removal of organic compounds (NOM, COD, TOC, DOC, AOX), pesticides, pathogens and color, and reduction of TDS from chemical industry wastewater [182], [183].
Specific:	Treatment of effluents for the purpose of water reuse [161].
	Purification of brine in chloralkali production [115].
	Removal of heavy metals from chemical production streams [111].
	Removal of AOX from wash-waters from the production of X-ray contrast media (iodine compounds) [187].
Textile	
General:	Removal of divalent and multivalent ions (Ca, Mg, bicarbonate, sulphate, phosphate, heavy metals), removal of organic compounds (NOM, COD, TOC, DOC, AOX), pesticides, pathogens and color, and reduction of TDS from textile wastewater [182], [183].
Specific:	Treatment of effluents for the purpose of water reuse [161].
	Dye desalting and concentration, dye recovery, optical brightening agent concentration and desalination [182].
	Removal of sulphate and chromium from textile wastewater [182].
	Caustic recovery, purification, and reuse [186].
	Removal/reduction of the following toxic contaminants found in textile industry wastewater (nonylphenol and nonylphenol ethoxylates, PAHs, brominated flame retardants, antimony trioxide, and PFAS) [118].
Primary Metals	
General:	Removal of divalent and multivalent ions (Ca, Mg, bicarbonate, sulphate, phosphate, heavy metals), removal of organic compounds (NOM, COD, TOC, DOC, PAH), and reduction of TDS from primary metals wastewater [182], [183].
Specific:	Treatment of effluents for the purpose of water reuse [161].
	Removal and recovery of heavy metals from primary metal wastewater streams [188].
Power	

Sector	Applications
General:	• Removal of divalent and multivalent ions (Ca, Mg, bicarbonate, sulphate, phosphate, heavy metals), removal of organic compounds (NOM, COD, TOC, DOC, PAH), and reduction of TDS from power industry wastewater [182], [183].
Specific:	• Treatment of effluents for the purpose of water reuse [161]. • Removal and recovery of heavy metals from power industry wastewater streams [188]. • Can be used as pretreatment to RO/ion exchange/ED for the softening and demineralization of boiler feed water and cooling tower makeup water [189]. • Treatment of boric acid wastewater in nuclear industry (boric acid permeates while radioactivity is rejected) [190]. • Used in nuclear fuel fabrication facilities to remove dissolved uranium ions from wash solutions [190].
Mining	
General:	• Removal of divalent and multivalent ions (Ca, Mg, bicarbonate, sulphate, phosphate, heavy metals), removal of organic compounds (NOM, COD, TOC, DOC), and reduction of TDS from mining industry wastewater [182], [183].
Specific:	• Treatment of effluents for the purpose of water reuse [161]. • Removal and recovery of heavy metals from mining industry wastewater streams [188], [129]. • Recovery of precious metals such as gold and silver [182]. • Treatment of wastewater streams like acid mine drainage and tailings (removal of toxic heavy metals, and harmful anions such as sulphate) [129], [191].
Real Estate	
General:	• Removal of divalent and multivalent ions (Ca, Mg, bicarbonate, sulphate, phosphate, heavy metals), removal of organic compounds (NOM, COD, TOC, DOC), pathogens, and reduction of TDS from real estate sector water and wastewater [182], [183].
Specific:	• Treatment of effluents for the purpose of water reuse (sanitary water) [161]. • Removal of endocrine disrupting compounds, pharmaceuticals, and personal care products from natural water and wastewater [182]. • Used in water softening to protect plumbing from scaling [192]. • Removal of toxic heavy metals [188]. • Removal of emerging contaminants such as PFAS from drinking water [193].

Economics

The CAPEX of an NF system is highly variable and depends on the systems configuration, design capacity, material of construction, feed wastewater quality, among other factors. In addition, the treatment of the concentrate stream might warrant additional investment depending on the contaminants present. Indicative CAPEX is 5,000 – 30,000 Euros per m^3/h design capacity [129].

OPEX includes energy consumption for pumping systems and chemical consumption for membrane cleaning and anti-scaling/fouling regimes. In addition, membrane replacement is a major cost to be taken into consideration as the life expectancy of NF membranes usually does not exceed 5 years, even under the strictest anti-fouling regimes [110]. Indicative OPEX is 0.2 – 0.6 Euros per m^3 [129].

Given the above, costs maybe be offset to some extent given the potential economic benefits that may result from reduced water consumption due to reuse and/or recovery of raw materials.

Real Scale Implementation Examples

Below are some real scale implementation examples of nanofiltration in various industries:

- Example 1 [194]: Full-scale implementation for the removal of sulphate from coal mine wastewater.

  A Coal Company's expansion project in China produces large quantities of mine wastewater. This wastewater cannot be directly discharged to natural water bodies and the requirement was to reduce sulphate concentration to within regulatory limits. The pretreatment to the NF system was designed to remove turbidity, heavy metals, TOC and it comprised of a clarifier with chemical dosing, multi-media filter, activated carbon filter followed by an ultrafiltration system. Four NF trains were installed to treat a total flow of 884 m^3/h with 85% recovery. The permeate stream had reduced sulphate concentrations from 1,200 mg/l to less than 10 mg/l.
- Example 2 [195]: Full-scale implementation of nanofiltration in large-scale municipal plant in Méry-Sur-Oise, France.

  At the beginning of the 90's, concerns emerged about the water quantity and quality at Méry-Sur-Oise water treatment plant. Organic matter, micropollutants and pesticides were on the rise, while it was also needed to partially reduce hardness content to improve taste. The NF system of 8 trains in a 3-Stage configuration with 108/54/28 pressure vessels, with 6 Dupont NF elements per vessel, running at 85% recovery. The NF system achieve up to 94% TOC rejection, over 90% color reduction, and total absence of coliforms and pesticides (30 types searched) in permeate. In the distribution system, the high removal of organics by NF allows a reduction of up to 25% of chlorine demand, therefore reducing as well trihalomethane's formation by half. NF allows as well up to 55% hardness reduction to satisfy demands about taste while reducing pipe corrosion and needs of remineralization. The plant capacity is 140,000 m^3/day.

Technology Providers

With regards to nanofiltration systems, the complete system is made of several components such as pumps, membranes, membrane housings, tanks, various instrumentations, and control systems in addition to the use of various chemicals. Herein, technology providers for complete NF skids and NF membranes in ENVITECC countries are provided as listed in Table 56.

Table 56: Nanofiltration Technology Providers.

Product Type	Country	Technology Provider	Technology Provider Website
With Offices in Europe and/or MENA Region			
NF Membranes	Europe	Alfa Laval	Link
NF Membranes	Europe/MENA	Dupont	Link
NF Membranes	Europe	Hydranautics/Nitto	Link
NF Membranes	Europe	Koch Separation Solutions	Link
NF Membranes	Europe	Mann-Hummel	Link
NF Membranes	Europe/MENA	Toray	Link
Local Suppliers in ENVITECC Countries			
NF Membranes	Lebanon	PWP	Link
NF Membranes	Morocco	Geissmann	Link
NF Membranes	Türkiye	Vatek	Link
NF Membranes	Türkiye	Aquamatch	Link

3.4. Reverse Osmosis

A membrane process involves the permeation of a liquid through a semi-permeable membrane resulting in two segregated streams which are the permeate stream and the concentrate stream. The driving force for this process is the pressure difference across the membrane.

Reverse osmosis (RO) membranes can hold back all particles down to the size of organic molecules and even ions as they possess the smallest pore size used in liquid/liquid separation (< 0.002 µm). Provided that the feed wastewater is particulate free, these membranes are mainly used when complete recycling of permeate and/or concentrate is desired. They allow water to pass through and retain the solute which includes salts, metal ions and certain organics [110].

Membranes are available in various materials and configurations. The optimum system for a particular application will depend on the nature of the wastewater since different materials have varying resistances to dissolved substances. For example, the polyamide-based membranes are normally superior to cellulose acetate-based membranes for the removal of trace organic molecules [110].

Even under the best pretreatment installations, membranes will foul and deteriorate in performance if cleaning is not ensured. Hence, membrane systems should be designed in such a way that those modules can be taken offline and cleaned chemically or mechanically [110].

Industrial membrane plants usually consist of three separate sections:

- Pre-treatment section where the feed is treated by clarification and subsequent filtration. Filtration can be achieved in stages with decreasing pore size.
- Membrane section where high-pressure is applied and wastewater flows across the membrane.
- Post-treatment section where the permeate is prepared for reuse or discharge while the concentrated brine is collected for further processing or disposal.

Membrane units are arranged as modules either in parallel to provide the necessary hydraulic capacity or in series to increase the degree of efficiency.

The utilization of RO systems offers a versatile solution in a range of applications including wastewater treatment, water reuse initiatives, compound recovery and purification/concentration processes.

RO systems are used to remove numerous types of contaminants which can include monovalent and divalent ions, heavy metals, pathogens, and organic compounds including toxic or inhibitory substances such as POPs [110].

Environmental Performance and Operational Data

Table 57 below summarizes key performance indicators for RO systems based on data retrieved from the literature. It should be emphasized that the ultimate performance of an RO system is highly dependent on the nature and characteristics of the incoming wastewater, type of membrane, operational procedures (antiscalant regimes, cleaning schedules, etc.), among others.

Table 57: Reverse Osmosis Key Performance Indicators.

Contaminant / KPI	Removal/Rejection Efficiency	Contaminant / KPI	Removal/Rejection Efficiency
Reference: [196]			
Sodium Fluoride	99%	Magnesium Chloride	99%
Sodium Cyanide	97%	Calcium Chloride	99%
Sodium Chloride	99%	Magnesium Sulphate	99%
Silica	98%	Nickel Sulphate	99%
Sodium Bicarbonate	99%	Copper Sulphate	99%
Sodium Nitrate	97%		
Reference: [129]			
Aluminum	95 – 99%	Ammonium	> 85%
Arsenic (V)	91 – 99%	Nickel	> 95%
Chloride	> 98%	Phosphorus	> 80%
Copper	> 95%	Selenium	91 – 99%
Iron	> 95%	Zinc	> 95%
Manganese	> 95%		
Reference: [110]			
Atrazine	84 – 97%	Trifluralin	99%
γ-Hexachlorocyclohexane	99%	Fenitrothion	99%
DDT	100%	Azinphos-methyl	98%
Aldrin	100%	Malathion	99%
Dieldrin	100%	Simazine	95%
Reference: [132]			
1,4-dioxane	96%	Methyl tert-butyl ether	97%
Alachlor	71 – 99%	Mevinphos	96%
Aldicarb	98%	Oxamyl	99%
Arsenic	75 – 99%	Per- and Polyfluoroalkyl Substances	83 – 99%
Carbofuran	76 – 90%	Perchlorate	78 – 100%
Cyanide	99%	Perfluorooctane Sulfonate	80 – 99%
Dichlorvos	95 – 99%	Perfluorooctanoic Acid	47 – 99%
Dicrotophos	96 – 99%	Radium	87 – 99%
Fenamiphos	99%	Ricin	99%
Fluoride	80 – 100%	Strontium	97 – 99%
Ibuprofen	92 – 99%	Strychnine	98 – 99%
Malathion	99%	Uranium	90%
Methomyl	96%	Vinclozolin	90%

Membrane treatment produces a waste stream (concentrate) of approximately 10% of the original feed volume, in which the target substances are present at levels approximately 10 times their concentration in the feed wastewater. An assessment needs to be made as to whether this residue can be recycled, disposed of, or needs further treatment. With organic substances, the concentration increase might improve the conditions for subsequent oxidative destruction processes. With inorganic substances, the concentration stage could be used as part of a recovery process. In both cases, the permeate water from a membrane process could potentially be reused or recycled in the industrial process, thus reducing water input and discharge [110].

RO systems consume energy and chemicals. Energy consumption is directly related to the flowrate and pressure requirements while chemical consumption is dependent on the tendency for fouling and frequency of chemical cleaning [110].

Sector-Specific Applications

Table 58 below lists several examples of sector specific applications for the use of reverse osmosis. In addition, it includes various contaminants that reverse osmosis is able to effectively target and remove as retrieved from the literature and/or advertised by technology providers.

Table 58: Reverse Osmosis Sector Specific Applications.

Sector	Applications
Food & Beverage	
General:	• Removal of monovalent, divalent, and multivalent ions (Na, Cl, Ca, Mg, bicarbonate, nitrate, phosphate, sulphate), removal of organic compounds (NOM, COD, TOC, DOC), pesticides, pathogens, color, and TDS from F&B wastewater [197].
Specific:	• Treatment of effluents for the purpose of water reuse [136]. • Dewatering and concentration of milk and whey [161]. • Concentration of thin cane and beet sugar, waste brine recycling from sugar decolorization, juice and tea concentration [184]. • Concentration of amino acid and fermentation products [185].
Pulp & Paper	
General:	• Removal of monovalent, divalent, and multivalent ions (Na, Cl, Ca, Mg, bicarbonate, nitrate, phosphate, sulphate), removal of organic compounds (NOM, COD, TOC, DOC, AOX), color, and TDS from P&P wastewater [197].
Specific:	• Treatment of effluents for the purpose of water reuse [136]. • Treatment and recycling of whitewater [163]. • Used in the treatment of boiler feed water [198].
Chemicals	
General:	• Removal of monovalent, divalent, and multivalent ions (Na, Cl, Ca, Mg, bicarbonate, nitrate, phosphate, sulphate, heavy metals), removal of organic compounds (NOM, COD, TOC, DOC, AOX), color, and TDS from chemical industry wastewater [197].
Specific:	• Treatment of effluents for the purpose of water reuse [136]. • Used for compound recovery such as solvents, acids, and other valuable chemicals from waste streams, reducing the need for new raw materials and minimizing waste [113]. • Steam purification and treatment and recycling of condensates [112].
Textile	
General:	• Removal of monovalent, divalent, and multivalent ions (Na, Cl, Ca, Mg, bicarbonate, nitrate, phosphate, sulphate, heavy metals), removal of organic compounds (NOM, COD, TOC, DOC, AOX), color, and TDS from textile industry wastewater [197].
Specific:	• Treatment of effluents for the purpose of water reuse [136].

Sector	Applications
	• Treatment of segregated streams from dyeing and desizing to allow water recovery and reuse [118]. • Removal/reduction of the following toxic contaminants found in the textile industry wastewater (nonylphenol and nonylphenol ethoxylates, PAHs, brominated flame retardants, antimony trioxide, and PFAS) [118]. • Recovery of dyes and chemicals from textile effluents [199].
Primary Metals	
General:	• Removal of monovalent, divalent, and multivalent ions (Na, Cl, Ca, Mg, bicarbonate, nitrate, phosphate, sulphate, heavy metals), removal of organic compounds (NOM, COD, TOC, DOC, PAH), and TDS from primary metals industry wastewater [197].
Specific:	• Treatment of effluents for the purpose of water reuse [136]. • Removal of dissolved metals from process streams of primary metals processes [123].
Power	
General:	• Removal of monovalent, divalent, and multivalent ions (Na, Cl, Ca, Mg, bicarbonate, nitrate, phosphate, sulphate, heavy metals), removal of organic compounds (NOM, COD, TOC, DOC, PAH), and TDS from power industry wastewater [197].
Specific:	• Treatment of effluents for the purpose of water reuse [136]. • If near coastal areas, seawater can be desalinated using RO for use in the power plants [125]. • Reduction of metals in scrubber wastewater [125]. • Used in the treatment of boiler feed water and in the polishing of condensate streams [200].
Mining	
General:	• Removal of monovalent, divalent, and multivalent ions (Na, Cl, Ca, Mg, bicarbonate, nitrate, phosphate, sulphate, heavy metals), removal of organic compounds (NOM, COD, TOC, DOC), and TDS from mining industry wastewater [197].
Specific:	• Treatment of effluents for the purpose of water reuse [136]. • Removal and recovery of heavy metals from mining industry wastewater streams [129]. • Treatment of wastewater streams like acid mine drainage and tailings (removal of toxic heavy metals, and harmful anions such as sulphate) [129], [191].
Real Estate	
General:	• Removal of monovalent, divalent and multivalent ions (Na, Cl, Ca, Mg, bicarbonate, nitrate, phosphate, sulphate, heavy metals), removal of organic compounds (NOM, COD, TOC, DOC), pesticides, pathogens, color, and TDS from real estate sector wastewater [197].
Specific:	• Treatment of effluents for the purpose of water reuse (e.g., sanitary water) [136]. • Water softening [201]. • Treatment of drinking water for the removal of various contaminants (heavy metals, PFAS, POPs) [201]. • Treatment of boiler feed water [201].

Economics

The CAPEX of an RO system is highly variable and depends on the systems configuration, design capacity, material of construction, feed wastewater quality, among other factors. In addition, the treatment of the concentrate stream might warrant additional investment depending on the contaminants present. Indicative CAPEX is 738 – 2029 Euros per 1 m^3/day design capacity [202].

OPEX includes energy consumption for pumping systems and chemical consumption for membrane cleaning and anti-scaling/fouling regimes. In addition, membrane replacement is major cost to be taken into consideration as the life expectancy of RO membranes usually does not exceed 3 to 5 years, even under the strictest anti-fouling regimes [110]. Indicative OPEX is 0.23 – 0.68 Euros per m^3 [202].

Given the above, costs maybe be offset to some extent given the potential economic benefits that may result from reduced water consumption due to reuse and/or recovery of raw materials.

Real Scale Implementation Examples

Below are some real scale implementation examples:

- Example 1 [181]: Full-scale implementation treatment of flue gas desulfurization wastewater.

  The motivation of the project is to achieve zero liquid discharge. The system consists of partial softening using a tubular microfiltration membrane system, followed by a nanofiltration treatment which is designed to separate out divalent ions (sulphate and residual hardness) from monovalent ions (Na, Cl, etc.). A second pass brackish water RO is used to polish the permeate, and the brine is sent to another higher pressure rated specialty RO unit before a final evaporation step to recover monovalent salt. Flow from NF separation to 2-pass RO is 36 m^3/h, flow from 2-pass RO to high-pressure RO is 12 m^3/h, NF separation recovery is up to 80% (in pilot), and 2-pass RO recovery is 67%. All reported ions had a removal rate of almost 100%.
- Example 2 [125]: Real-scale implementation on wastewater from furnace flue-gas condensate.

  The process is described in the BREF under a technique for the reduction of metal emission. A plant referred to as LiqTech has implemented membrane filtration to reduce metals in the scrubber wastewater. Wastewater from the wet scrubbers (furnace flue-gas condensate) are treated with silicon carbide ceramic membranes. The operating cost and environmental impact can be significantly reduced when reusing the treated scrubber water in a closed loop, i.e., the polluted liquid is passed through ceramic membranes followed by reverse osmosis membranes. When reusing the treated water, an estimated 80% reduction in clean water usage can be achieved. In addition, wastewater discharge and chemical sludge handling, and their associated costs could also be reduced by 90%.
- Example 3 [187]: Full-scale implementation in an API plant investigated under the BREF.

  Wastewater streams from the manufacture of highly active ingredients are pretreated by means of reverse osmosis. The guiding parameter to track the halogenated compounds is AOX. Achieved environmental benefits include 99.99% removal of AOX.
- Example 4 [203]: Pilot-scale implementation at an oil refinery.

  An oil refinery located in Texas, USA was interested in reusing wastewater as process water to achieve two objectives: reduce its potable water consumption and reduce wastewater disposal costs. A pilot study was performed to demonstrate the feasibility of reusing treated wastewater as makeup water for boiler feed and cooling tower. The pilot system consisted of three unit operations: ultrafiltration, strong acid cation exchange softening and reverse osmosis. The pilot installation operated successfully and consistently achieved reuse water quality that far exceeded the requirements for boiler feed water and cooling tower makeup. These results indicated that the current amount of wastewater being discharged can be reduced by more than 50% with the application of this water reuse solution. Abatement efficiencies for different contaminants include 97% chloride, 88% iron, 83% manganese, 89% nitrate, 91% phosphate, 99% strontium, and 99% TDS.

Technology Providers

With regards to reverse osmosis systems, the complete system is made of several components such as pumps, membranes, membrane housings, tanks, various instrumentations, and control systems in addition to the use of various chemicals. Herein, technology providers for complete RO skids and RO membranes in ENVITECC countries are provided as listed in Table 59.

Table 59: Reverse Osmosis Technology Providers.

Product Type	Country	Technology Provider	Technology Provider Website
With Offices in Europe and/or MENA Region			
RO Membranes	Europe	Alfa Laval	Link
RO Membranes	Europe/MENA	Dupont	Link
RO Membranes	Europe	Hydranautics/Nitto	Link
RO Membranes	Europe	Koch Separation Solutions	Link
RO Membranes	Europe	Mann-Hummel	Link
RO Membranes	Europe/MENA	Toray	Link
Local Suppliers in ENVITECC Countries			
RO Systems	Albania	Albuji	Link
RO Systems	Albania	EWT	Link
RO Systems	Albania	Ecosoft	Link
RO Systems	Bosnia and Herzegovina	Adepto	Link
RO Systems	Bosnia and Herzegovina	Nobel	Link
RO Systems	Bosnia and Herzegovina	Nobilis	Link
RO Systems	Egypt	Epeco	Link
RO Systems	Egypt	Mid Water	Link
RO Systems	Egypt	Water Tech	Link
RO Systems	Lebanon	Water Frame	Link
RO Systems	Lebanon	PWP	Link
RO Systems	Lebanon	Anhar	Link
RO Systems	Montenegro	Nobel	Link
RO Systems	Montenegro	Ening	Link
RO Systems	Morocco	Casa Merchants	Link
RO Membranes	Morocco	Geissmann	Link
RO Systems	Morocco	Monde De L’Eau	Link
RO Systems	Tunisia	Ideale Eau	Link
RO Systems	Tunisia	ETE	Link
RO Systems	Tunisia	ThermEco	Link
RO Systems	Türkiye	Vatek	Link
RO Systems	Türkiye	Angstrom	Link
RO Systems	Türkiye	Aquamatch	Link

4. Green Technology Selector Platform

Within the context of the ENVITECC Programme, the GTS platform can play a crucial role in disseminating the findings of the Wastewater Technology Guide. The identified advanced technologies for sustainable wastewater management can be made available on the GTS platform, providing businesses in the ENVITECC countries with easy access to this information. This will support the overall goal of the ENVITECC Programme to accelerate the adoption of technologies for reducing pollution, improving water management and treatment, and improving chemicals and waste management across the Mediterranean region.

Engicon completed extensive market research to identify currently available products of the advanced wastewater technologies, namely nanofiltration and reverse osmosis, within the ENVITECC market.

Complementing the information provided in Section 3.3 on NF and Section 3.4 on RO, additional technical information have been provided including typical operating configurations, fouling mechanisms and cleaning requirements, membrane materials and a brief on membrane selection criteria.

A longlist of technology providers of available NF and RO membranes in the market have been prepared by Engicon as part of this assignment. The longlist includes product attributes to facilitate the onboarding of the products onto the GTS platform. These attributes align with the GTS Platform's vision of promoting technologies and products that yield significant environmental benefits, minimize chemical usage, and exhibit high energy efficiency. The longlist is structured to include the following information:

- **S.N.:** provides a unique serial number for the listed membranes.
- **Technology:** identifies the membranes technology as either NF or RO.
- **Technology Provider:** provides the commercial name of the technology provider.
- **Membrane Model:** provides the membranes model name/number as advertised by the technology provider.
- **Membrane Type:** provides the material of which the membrane is made of as advertised by the technology provider.
- **Membrane Outside Diameter:** provides the outside diameter of the membrane as advertised by the technology provider which is usually standardized to fit commercially available pressure vessels.
- **Membrane Active Area:** provides the actual and useful measured surface area of the membrane as advertised by the technology provider.
- **Permeate Flowrate:** provides the membranes achievable permeate flowrate under the specific test conditions as advertised by the technology provider.
- **Application:** provides the membranes use case areas/sectors as advertised by the technology provider.
- **Product Website:** provides a link to the membranes webpage.
- **Product Datasheet:** provides a link to the membranes datasheet.

- **Target Pollutants:** provides the membranes performance with regards to compound rejection including rejection efficiencies as advertised by the technology provider. Technology providers usually advertise the membranes stabilized and minimum salt rejection under specific test conditions. In certain instances, technology providers might provide rejection values for other compounds, however, the availability of such information was found to be limited.
- **Energy Consumption:** provides any energy efficiency characteristics of the membrane as advertised by the technology provider. Ideally, one would look for the specific energy consumption per cubic meter of product water, however, the availability of such information was found to be limited. This may be due to the variability of such figures from one application to the other.
- **Chemical Consumption/Cleaning Requirements:** provides any information regarding the reduction in chemical usage offered by the use of the membrane as advertised by the technology provider. Typically, fouling resistant membranes would require less frequent cleaning to maintain their performance and hence would reduce the amount of chemicals used.
- **Real Scale Applications:** provides any real scale applications or use cases where the membrane has been used in the industry. It was found that this type of information is not readily available or not publicly disclosed due to confidentiality.

Appendices

Appendix A – Major Sectorial Wastewater Contaminants Longlist

Appendix B – Water and Wastewater Technologies Longlist

Appendix C – Water and Wastewater Management Practices Longlist

Appendix A – Major Sectoral Wastewater Contaminants Longlist

Typical Wastewater Contaminants	Industrial Sector						
	Food & Beverage	Pulp & Paper	Chemicals	Textile	Primary Metals	Power	Mining
Fats, Oils, and Grease (FOG)	x						
Biochemical Oxygen Demand (BOD)	x	x	x	x	x	x	
Chemical Oxygen Demand (COD)	x	x	x	x	x	x	x
Total Suspended Solids (TSS)	x	x	x	x	x	x	x
Total Dissolved Solids (TDS)	x	x	x	x	x	x	x
Total Phosphorus (TP)	x	x	x	x	x		x
Total Nitrogen (TN)	x	x	x	x	x	x	x
Volatile Organic Compounds (VOC)	x	x	x	x		x	
Adsorbable Organically Bound Halogens (AOX)		x	x	x			
Polycyclic Aromatic Hydrocarbons (PAH)				x	x	x	
Alkylphenol Ethoxylates (APEO)				x			
Arsenic (As)			x		x	x	x
Cadmium (Cd)			x		x	x	x
Chromium (Cr)			x	x	x	x	x
Mercury (Hg)			x		x	x	x
Nickel (Ni)			x	x	x	x	x
Lead (Pb)			x		x	x	x
Zinc (Zn)			x	x	x	x	x
Copper (Cu)			x	x	x	x	x
Vanadium (V)			x		x	x	
Selenium (Se)						x	x
Iron (Fe)			x		x		x
Tin (Sn)					x	x	
Antimony (Sb)				x		x	x
Cobalt (Co)						x	
Manganese (Mn)						x	x
Normally Occurring Radioactive Material							x
Fluoride (F^-)			x		x	x	
Chloride (Cl^-)	x		x		x	x	x
Chlorate (ClO_3^-)		x	x				
Bromate (BrO_3^-)			x				
Thiocyanate (SCN^-)			x		x		
Cyanide (CN^-)			x		x	x	x
Sulfide (S^{2-})			x	x	x	x	
Sulfate (SO_4^{2-})	x		x	x	x	x	x
Sulfite (SO_3^{2-})			x	x		x	
Phenols	x	x	x	x	x	x	

Typical Wastewater Contaminants	Industrial Sector						
	Food & Beverage	Pulp & Paper	Chemicals	Textile	Primary Metals	Power	Mining
Hydrocarbons			x	x	x	x	
Hydrogen Sulfide (H_2S)			x		x		
Chelating Agents		x		x			
Urea				x			
Pesticides	x		x	x			
Pathogens	x						
Color	x	x	x	x			
Odor	x	x		x			
pH	x	x	x	x	x	x	x
References	[104] [105]	[107] [108]	[110] [111] [112] [113] [114] [115] [116]	[118]	[122] [121] [123]	[125]	[129]

Appendix B – Water and Wastewater Treatment Techniques Longlist

Treatment Technique [204]		Description of the Technique [204]	Typical Wastewater Contaminants Targeted by the Treatment Technique														Other Specific Water & Wastewater Contaminants [132]
			Organic				Inorganic				Nutrient		Pathogens	Physical Property			
								TDS									
			FOG	BOD	COD	VOC	TSS	Monovalent	Divalent	Heavy Metals	TP	TN		Color	pH	Odor	
Physical Treatment																	
Aeration	Aeration Channel, Aerobic Polishing Cell	Providing contact with air or pure oxygen to increase dissolved oxygen (DO) in wastewater.				x							x			x	1,2,3-trichloropropane, 1,2-Dibromoethane, Benzene, Cis-1,2-dichloroethylene
Ballasted Clarification	BioMag, CoMag, Enhanced Settling, High Rate Settling, Actiflo	Improves gravitational settling rates by addition of a weighing agent to the clarifier, typically magnetite or sand.	x				x										
Capacitive Deionization	Electro-sorption	Removal of dissolved ions through an electrochemical mechanism.						x	x	x	x	x					4-Nonylphenol, Chlortetracycline, Perchlorate
Centrifugal Separators	(Liquid) Hydrocyclone	Mechanical separation of liquids or particles of different densities. Used to separate oil from water and separate light from dense solids.	x				x										
Clarification	Settling, Sedimentation	Separation of suspended particles from water by gravitational settling.	x				x										
Controlled Hydrodynamic Cavitation	Mechanical Energy Device	Device that uses mechanical energy to prevent biofouling, scale, and corrosion. The high temperatures and physical forces generated promote chemical reactions, oxidize organic compounds, and kill pathogens. Cavitation is the formation and implosion of cavities (bubbles) in a liquid.			x			x	x				x				
Crystallization	Fluidized Bed Crystallization	Crystallization describes the formation of solid crystals precipitating from a solution. It can be applied post-evaporation to create a solid waste product or to recover a product in the wastewater. When used for product recovery, crystallization combines four treatment steps–coagulation, flocculation, sludge/water separation, and dewatering. High-purity, reusable water is also produced.						x	x	x							

Treatment Technique [204]		Description of the Technique [204]	Typical Wastewater Contaminants Targeted by the Treatment Technique														
			Organic				Inorganic				Nutrient		Pathogens	Physical Property			Other Specific Water & Wastewater Contaminants [132]
								TDS									
			FOG	BOD	COD	VOC	TSS	Monovalent	Divalent	Heavy Metals	TP	TN		Color	pH	Odor	
Degasification	Membrane Degasification, Forced Draft Degasification	Removal of dissolved gases from water by pressure reduction, membrane degasification, or an unspecified method. This includes heating to remove a gas. If heating is used to vaporize water, can be considered under Evaporation.															Nitrogen, Oxygen, Carbon Dioxide
Dissolved Air Flotation	N/A	Air is dissolved under pressure and then released at atmospheric pressure in a tank. The released air creates bubbles which adhere to suspended solids, causing the solids to float to the surface where they can be removed by skimming. Removes suspended solids, oil, and grease	x			x	x										
Dissolved Gas Flotation	N/A	Same process as Dissolved Air Flotation, but uses gases other than air (e.g., natural gas, nitrogen).	x			x	x										
Distillation	N/A	Contaminated water is heated to form steam, leaving inorganic compounds and large, non-volatile organic molecules behind. The steam is then condensed, forming purified water. Distillation requires input of energy and collection of the purified water.	x	x	x		x	x	x	x	x	x	x				
Electrocoagulation	N/A	Entails passing the wastewater across metal electrodes. EC is used to remove colloids, heavy metals, and emulsified oils. The direct current solubilizes metal ions and destabilizes charged particles, promoting coagulation and flocculation.	x	x	x		x			x			x	x			
Electrodialysis	Electrodialysis Reversal (EDR)	Involves moving ions in a potential field across alternating polymeric anion- and cation-exchange membranes. A potential difference applied across the membranes traps ions and separates a brine waste stream from purified water. Electrodialysis works best for removing low molecular weight charged species.						x	x	x							Chromium, Fluoride, Perchlorate

Treatment Technique [204]		Description of the Technique [204]	Typical Wastewater Contaminants Targeted by the Treatment Technique														
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								TDS									
			FOG	BOD	COD	VOC	TSS	Monovalent	Divalent	Heavy Metals	TP	TN		Color	pH	Odor	
Evaporation	N/A	Water is vaporized and sometimes condensed for reuse. The remaining product is concentrated brine containing the dissolved solids from the original wastewater. The process may be carried out naturally in solar (shallow) evaporation ponds or through the use of commercially available evaporation equipment. The brine may be further concentrated during the crystallization process.	x	x	x		x	x	x	x	x	x	x				
Flow Equalization	Buffer Tank, Flow Control, Flow Balance	A basin, lagoon, tank, or reactor that serves to control a variable flow of wastewater to achieve a near constant flow into the treatment system or between units.															
Mechanical Pre-Treatment	Screen, Bar, Rack, Grit Chamber, Comminuter, Grinder	Physical removal of debris and coarse solids. This is the first step in wastewater treatment, which serves to protect downstream treatment equipment.	x	x			x										
Membrane Distillation	N/A	A separation process where a temperature difference across a hydrophobic membrane separates two aqueous solutions. Water vapor is driven through the membrane by vapor pressure, induced by the temperature difference, and condenses.						x	x	x							
Oil/Water Separation	API Separators	Removal of gross quantities of oil and suspended solids by skimming and collecting oil from the surface of the wastewater.	x				x										
Stripping	Air or Gas Stripping	The removal of substances with equilibrium vapor pressures at ambient temperatures, such as ammonia and many volatile organic compounds (VOCs).				x						x				x	1,2,3-trichloropropane, 1,2-Dibromoethane, Benzene, Cis-1,2-dichloroethylene, Methyl tert-butyl ether, Tetrachloroethylene
Surface Impoundment	N/A	Natural or man-made topographic depression with a dammed location that is primarily made of earthen material and used to volatilize and/or settle materials.	x	x	x	x	x										

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								TDS									
			FOG	BOD	COD	VOC	TSS	Monovalent	Divalent	Heavy Metals	TP	TN		Color	pH	Odor	
Ultrasound	Sonication	High frequency bandwidth of sound applied to agitate particles in solution and disrupt cell membranes. Used in water storage facilities to suppress algal growth and biofilm formation.											x				
Biological Treatment																	
Aerobic Biological Treatment	Aerated Biological Removal, Aerobic Digestion	Biodegradable organic compounds in wastewater are consumed by microorganisms. This process is aerated.		x	x						x	x					
Aerobic Fixed Film Biological Treatment	Attached Growth, Fixed Bed Reactor, Rotating Biological Contactor, Trickling Filter, Fluidized Bed Reactor	Microorganisms attach to inert media. This process is aerated.		x	x						x	x					
Aerobic Suspended Growth	Activated Sludge, Aerobic Lagoon	Biodegradable organic compounds in wastewater are consumed by microorganisms. The microorganisms are suspended within the wastewater, creating a sludge that is separated from the water (during clarification). This process is aerated.		x	x						x	x					
Anaerobic Biological Treatment	Non-Aerated, Facultative	A biological treatment process that is non-aerated, hence, without oxygen.		x	x						x	x					
Anaerobic Fixed Film Biological Treatment	Attached Growth, Fixed Bed Reactor, Rotating Biological Contactor, Trickling Filter, Fluidized Bed Reactor	Microorganisms attach to inert media.		x	x						x	x					
Anaerobic Membrane Bioreactor	N/A	Combination of suspended growth biological treatment under low or zero dissolved oxygen conditions and ultrafiltration.		x	x		x				x	x					

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			FOG	BOD	COD	VOC	TSS	TDS			TP	TN		Color	pH	Odor	
								Monovalent	Divalent	Heavy Metals							
Anaerobic Suspended Growth	Anaerobic Lagoon	Biodegradable organic compounds in wastewater are consumed by microorganisms. The microorganisms are suspended within the wastewater, creating a sludge that is separated from the water.		x	x						x	x					
Bioaugmentation	N/A	Addition of specialized microbial strains in a bioreactor to enhance the ability of the microbial community to respond to operational conditions and/or degrade compounds.		x	x						x	x					
Biofilm Airlift Suspension Reactor	Airlift Bioreactor	Pneumatic device with defined channels for fluid flow. Air pumped into the unit forces the fluid to flow through channels (internal or external loops). Usually will contain gas, solid, and liquid phases.		x	x						x	x					
Biological Activated Carbon Filters	N/A	GAC, sand, or other filter media with microbial growth that can remove residual pollutants via filtration, adsorption, biodegradation, and bioregeneration.		x	x	x	x			x	x	x					Alachlor, Arsenic, Benzene, Ibuprofen, Methyl tert-butyl ether, Natural Organic Matter, Nitrobenzene
Biological Nutrient Removal	Modified Ludzack-Ettinger (MLE) Process	General term for technologies designed to remove nitrogen species from wastewater.		x	x							x					
Constructed Wetlands	Reed Bed, Artificial Wetland, Peat Land	Application of natural processes and use of vegetation to remove BOD, nutrients, and suspended solids. “Green” technology that can minimize energy used for water treatment.		x	x		x				x	x					
Denitrification Filters	N/A	Granular-media filtration beds that support growth of denitrifying bacteria. These units reduce nitrate to nitrogen gas and remove suspended solids.		x	x		x					x					
Enhanced Biological Phosphorus Removal	Enhanced Biological Phosphorus Uptake	Use of phosphate-accumulating organisms to store phosphate within the cell. Phosphate removed in waste sludge.		x	x						x						

Treatment Technique [204]		Description of the Technique [204]	Typical Wastewater Contaminants Targeted by the Treatment Technique														
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								TDS									
			FOG	BOD	COD	VOC	TSS	Monovalent	Divalent	Heavy Metals	TP	TN		Color	pH	Odor	
Granular Sludge Sequencing Batch Reactor	N/A	Aerobic biological treatment with enhanced sludge settling by formation of granular sludge, without the use of carrier materials. Granular sludge developed by selection of biomass with short settling times.		x	x						x	x					
Integrated Fixed Film Activated Sludge	N/A	Carrier media added to an activated sludge system to increase loadings without increasing the plant footprint. Often used for retrofits.		x	x						x	x					
Membrane Bioreactor	N/A	Combination of aerobic suspended growth biological treatment and ultrafiltration. Ultrafiltration replaces the use of secondary clarifiers (solids separation) in conventional WWTPs. Can be used to reduce BOD, TSS, nitrogen, and phosphorus.		x	x		x				x	x					
Moving Bed Bioreactor	N/A	A hybrid suspended, growth-fixed film system. "Biocarrier" media are provided in the unit for the microorganisms to grow on. Increases the effective surface area for reaction while reducing the footprint of the system.		x	x						x	x					
Chemical Treatment																	
Advanced Oxidation Processes	Supercritical Water Oxidation, Catalytic Oxidation, Photo Catalysis (UV + TiO2), Fenton's Reagent	Various mechanisms to oxidize organic materials.		x	x	x							x	x		x	1,4-dioxane, 17a-ethynyl estradiol, Benzene, Tebuconazole
Alkaline Chlorination	N/A	Used to destroy cyanides. Most often the process is operated in two stages, with separate tanks for each stage. Destruction of dilute solutions of cyanide by chlorination can be accomplished by direct addition of sodium hypochlorite (NaOCl), or by addition of chlorine gas plus sodium hydroxide (NaOH) to the wastewater.															Cyanide

Treatment Technique [204]		Description of the Technique [204]	Typical Wastewater Contaminants Targeted by the Treatment Technique														Other Specific Water & Wastewater Contaminants [132]
			Organic				Inorganic				Nutrient		Pathogens	Physical Property			
								TDS									
			FOG	BOD	COD	VOC	TSS	Monovalent	Divalent	Heavy Metals	TP	TN		Color	pH	Odor	
Chemical Disinfection	Hydroxyl Radical, Oxygen, Hydrogen Peroxide, Chlorine Species, Chlorine Dioxide, Halogens	Use of chemicals to disinfect (destroy pathogens in) wastewater. Used when referring to oxidation of pollutants.											x			x	Cryptosporidium, Methiocarb, S. typhi, V. cholerae
Chemical Nitrogen Removal	N/A	Redox reaction to remove nitrogen from water or convert between different forms of nitrogen.										x					
Chemical Oxidation	Hydrogen Peroxide, Permanganate, Chlorine, Bleach	Addition of chemicals (in any phase) to oxidize organic compounds. Can be used to change the oxidative state of certain elements.		x	x					x				x		x	17a-ethynyl estradiol, 4-Nonylphenol, Arsenic, B. anthracis, Carbofuran, Diazinon, Disulfoton, Diuron, E. coli O157, Glyphosate, Malathion, Metolachlor Degradates, Microcystins, Molinate, Permethrin, Terbufos
Chemical Phosphorous Removal	N/A	Addition of metal-salts, most commonly alum, to precipitate phosphorus species out of solution.									x						
Chemical Precipitation + Charge Neutralization	Precipitation, Coagulation and Flocculation	Process to remove suspended solids from water. Chemical addition first neutralizes charged particles (coagulation) and promotes particle adhesion to form large, visible clumps (flocculation) that can then settle out of the wastewater. This term is also used for the addition of lime, alum, ferric sulphate, or other precipitants to remove soluble metals from solution by forming insoluble compounds.					x			x	x	x	x	x			Arsenic, Chromium, Cryptosporidium, Fluoride, Mercury, Uranium
Dechlorination	N/A	The process of removing residual chlorine from disinfected wastewater prior to discharge into the environment. Sulfur dioxide is most commonly used. Not to be confused with degradation of chlorinated organics.						x									

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			Organic				Inorganic				Nutrient			Physical Property			Other Specific Water & Wastewater Contaminants [132]
								TDS									
			FOG	BOD	COD	VOC	TSS	Monovalent	Divalent	Heavy Metals	TP	TN	Pathogens	Color	pH	Odor	
Gasification	Downdraft, Updraft or Fluidized Bed Gasifier	Thermo-chemical process to convert carbon-containing biosolids into gas (carbon dioxide and methane) and energy. Resulting energy can be used for heating. Gases are used to generate fuels, electricity, and heat. Gasification also reduces the volume of solids for disposal.		x	x	x											
Hydrolysis, Alkaline or Acid	N/A	Addition of an acid or base (e.g., sodium or potassium hydroxide) to enhance biodegradability of organic substances. Used as a pre-treatment step before biological treatment and to reduce the toxicity of pesticides.		x	x												Pesticides
Ion Exchange	Softening, Deionization	Ion exchange is a physical-chemical process in which ions are swapped between a solution phase and a solid resin phase. Different resins are used to target different charged particles. Commonly used for softening (removing dissolved calcium and magnesium) and nitrate removal.						x	x	x		x					Arsenic, Chlortetracycline, Chromium, Cobalt, Cyanide, Fluoride, Mercury, Per- and Polyfluoroalkyl Substances, Perchlorate, Perfluorooctane Sulfonate, Perfluorooctanoic Acid, Radium, Strontium, Uranium
Liquid Extraction	(Flotation) Liquid-Liquid Extraction, Solvent Extraction	Separation of chemicals based on different solubilities in two solutes. Allows recovery of the chemical from wastewater.															
Neutralization	Acid or Alkalis	Adjustment of the pH of the wastewater at neutral level (approximately pH 7) by the addition of chemicals.													x		
Ozonation	Advanced Oxidation Process	Ozone is a highly unstable gas used to either oxidize organic substances or disinfect wastewater. It must be produced onsite for immediate use in a contact chamber.		x	x	x							x	x		x	1,4-dioxane, 17a-ethynyl estradiol, 4-Nonylphenol, Acetochlor, Acetochlor Degradates, Alachlor, Alachlor Degradates, Benzene, Carbofuran, Cryptosporidium, Cyanide, Diazinon, Dichlorvos, Diuron, Glyphosate, Malathion, Methomyl, Methyl tert-butyl ether, Metolachlor, Microcystins, Nitrobenzene, Propoxur, Ricin, Strychnine, Vinclozolin

Treatment Technique [204]		Description of the Technique [204]	Typical Wastewater Contaminants Targeted by the Treatment Technique														
			Organic				Inorganic				Nutrient		Pathogens	Physical Property			Other Specific Water & Wastewater Contaminants [132]
								TDS									
			FOG	BOD	COD	VOC	TSS	Monovalent	Divalent	Heavy Metals	TP	TN		Color	pH	Odor	
UV	Ultraviolet Light or Radiation	Ultraviolet radiation penetrates the wastewater to oxidize organics and/or disinfect. Used as a last, polishing step in wastewater treatment. May be used with chemical oxidants such as peroxide and ozone.				x							x			x	Acetochlor, B. anthracis, Benzene, Carbofuran, Cryptosporidium, Cyclonite (RDX), Diazinon, Diuron, E. coli O157, Methomyl, Methyl tert-butyl ether, Nitrobenzene, Propoxur, Ricin, S. typhi, V. cholerae
Wet Air Oxidation	N/A	The oxidation of soluble or suspended components in water using oxygen as the oxidizing agent. Air is used as the source of oxygen.		x	x	x					x	x					Iron, Manganese, removal of carbon dioxide, taste and odor causing substances, VOCs and volatile SOCs, ammonia, trihalomethanes, pesticides, herbicides, and gases such as methane, hydrogen sulfide, and radon.
Zero Valent Iron	nZVI	Granular or nanoscale ZVI is used to remove metals by adsorption and reductive precipitation mechanisms. Utilized through a separate reactor unit. Similar configuration to granular-media filtration.								x							Nitrobenzene, Simazine and Simazine Degradates
Sorption																	
Adsorptive Media	N/A	Materials other than activated carbon used to remove pollutants via surface adhesion e.g., activated alumina, iron modified activated alumina, iron-based media and iron modified resin, titanium-based media and zirconium-based media, and minerals such as goethite, magnetite, etc.				x				x				x		x	1,2-Dibromoethane, 17a-ethynyl estradiol, Acetochlor, Alachlor, Arsenic, Benzene, Carbofuran, Chlortetracycline, Chromium, Cobalt, Fluoride, Mercury, Methyl tert-butyl ether, Nitrobenzene, Nitrofen, Per- and Polyfluoroalkyl Substances, Perfluorooctane Sulfonate, Perfluorooctanoic Acid, Radium, Strontium, Uranium

Treatment Technique [204]		Description of the Technique [204]	Typical Wastewater Contaminants Targeted by the Treatment Technique														
			Organic				Inorganic				Nutrient		Pathogens	Physical Property			Other Specific Water & Wastewater Contaminants [132]
								TDS									
			FOG	BOD	COD	VOC	TSS	Monovalent	Divalent	Heavy Metals	TP	TN		Color	pH	Odor	
Granular Activated Carbon Adsorption	N/A	Uses the physical/chemical adsorption process to remove soluble contaminants from wastewater. GAC is a highly effective adsorbent due to its large surface area and high porosity. Used to remove organics and some metals and for taste and odor control.				x				x				x		x	1,2-Dibromoethane, 17a-ethynyl estradiol, 4-Nonylphenol, Acetochlor, Alachlor, Aldicarb, Arsenic, Benzene, Carbofuran, Chlortetracycline, Chromium, Cis-1,2-dichloroethylene, Cobalt, Cyclonite (RDX), Dichlorvos, Dicrotophos, Mercury, Methomyl, Methyl tert-butyl ether, Mevinphos, Natural Organic Matter, Oxamyl, Per- and Polyfluoroalkyl Substances, Perchlorate, perfluorooctane Sulfunate, Perfluorooctanoic Acid, Strychnine, Tetrachloroethylene
Powdered Activated Carbon	N/A	Same removal mechanisms as GAC, but finer particles (<= 1.0 mm diameter).				x				x				x		x	17a-ethynyl estradiol, Acetochlor, Acetochlor Degradates, Alachlor, Alachlor Degradates, Fluoride, Metolachlor, Metolachlor Degradates, Microcystins, Natural Organic Matter, Per- and Polyfluoroalkyl Substances, Perfluorooctane Sulfonate, Perfluorooctanoic Acid, Simazine and Simazine Degradates, Strontium
Media Filtration																	
Bag and Cartridge Filtration	N/A	Used to remove suspended solids, typically in systems with lower flow rates. Filter media are shaped as bags or cylindrical cartridges.					x						x				
Cloth Filtration	Cloth Media (Disc) Filter	Water is passed through a cloth medium to remove solids. Cloth is often shaped into discs.					x						x				
Granular-Media Filtration	Conventional, Multi-Media, or Sand Filtration	Removal of suspended solids is accomplished by passing wastewater through a filter bed of granular media. Media may include sand, walnut shells, and steel slag.					x						x				Carbofuran, Cryptosporidium, Microcystins

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								TDS									
			FOG	BOD	COD	VOC	TSS	Monovalent	Divalent	Heavy Metals	TP	TN		Color	pH	Odor	
Membrane Filtration																	
Forward Osmosis	Engineered or Manipulated Osmosis	Water transfer through a selectively permeable membrane driven by the osmotic pressure difference across the membrane. Water is drawn across a membrane to a solution with a higher concentration (relative to the wastewater). The resulting separated water must then be further treated to produce a high-quality effluent.						x	x	x							
Micro-Membrane Filtration	Microfiltration	Filtration methods that remove particles as small as 100 nm. Many molecules are within this size range.					x						x				Cryptosporidium
Ultra-Membrane Filtration	Ultrafiltration	Filtration methods that remove particles as small as 10 nm. Many molecules are within this size range.					x						x				Cryptosporidium, Diuron, Microcystins, Natural Organic Matter
Nanofiltration	N/A	A membrane filtration method used to remove particles as small as 1 nm from wastewater. This includes divalent and large monovalent ions (e.g., heavy metals). Used for desalination and softening.				x	x		x	x			x	x			17a-ethynyl estradiol, 4-Nonylphenol, Arsenic, Chromium, Cryptosporidium, Cyanide, Dacthal and Dacthal Degradates, Diuron, Fluoride, Ibuprofen, Mercury, Methyl tert-butyl ether, Microcystins, Natural Organic Matter, Per- and Polyfluoroalkyl Substances, Perchlorate, Perfluorooctane Sulfonate, Perfluorooctanoic Acid, Simazine and Simazine Degradates
Reverse Osmosis	N/A	A membrane filtration method used to remove small ions (e.g., Na+) from water. Requires a high-pressure hydraulic pressure gradient to counteract the osmotic pressure gradient that would otherwise favor movement of water into (instead of out of) the concentrated wastewater or saltwater.				x	x	x	x	x	x	x	x	x			1,4-dioxane, Alachlor, Aldicarb, Arsenic, Carbofuran, Cyanide, Dichlorvos, Dicrotophos, Fenamiphos, Fluoride, Ibuprofen, Malathion, Methomyl, Methyl tert-butyl ether, Mevinphos, Oxamyl, Per- and Polyfluoroalkyl Substances, Perchlorate, Perfluorooctane Sulfonate, Perfluorooctanoic Acid, Radium, Ricin, Strontium, Strychnine, Uranium, Vinclozolin

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			FOG	BOD	COD	VOC	TSS	TDS			TP	TN		Color	pH	Odor	
								Monovalent	Divalent	Heavy Metals							
Sludge Treatment																	
Sludge Conditioning	Inorganic Coagulants, Organic Flocculants	Sludge solids are treated with chemicals or various other means to prepare the sludge for dewatering processes, in other words, to improve dewatering characteristics of the sludge.															Sludge handling, treatment, and disposal
Sludge Stabilization	Anaerobic Digestion, Aerobic Digestion, Vermistabilization, Composting	Chemical or biological process that stops the natural fermentation of the sludge.															
Sludge Thickening	Gravity Thickening, Dynamic Thickening	The solids content of sludge is increased by removing a portion of the liquid fraction.															
Sludge Dewatering	Belt Filter, Centrifuge, Frame Filter Press	Separation of sludge into liquid and solid components.															
Sludge Drying	Convective, Conductive, Solar	Reduction of water content in sludge by vaporization of water to the air.															

Appendix C – Water and Wastewater Management Practices Longlist

Management Practice Description [205]	Management Practice Objective			
	Water Conservation	Reduction of Wastewater Emissions	Wastewater Treatment	Wastewater Reuse
Development of plant performance benchmarks to evaluate its performance and assist in the identification of areas where water consumption and wastewater generation can be minimized.	x	x		
Changes in operational procedures that can be implement at no or minimal cost to reduce water consumption and wastewater generation (e.g., use pre-clean and dry cleanup methods before wet cleaning to prevent adding additional waste to the wastewater stream; place catch pans under potential overflows/leaks to collect high strength emissions and dispose separately; eliminate or decrease the concentration of certain pollutants; etc.).	x	x	x	
Implementation of operational and process monitoring opportunities (e.g., training and awareness programs for employees on how to use water efficiently; installation of water meters to monitor water consumption and wastewater generation; installation of process parameter sensors, etc.).	x	x	x	
Implementation of water reuse or recycling measures (e.g., reuse of process water wherever possible; eliminate once-through cooling water systems by a closed loop system; treatment of generated wastewater onsite and reuse in applicable processes; etc.).	x	x	x	x
Segregation of wastewater streams according to level and type of contamination. Segregated streams can be investigated for potential treatment and reuse.	x		x	x
Re-evaluate washing, rinsing, and cleaning procedures (e.g., use of high-pressure spray washers and nozzles instead of hoses, etc.).	x	x	x	
Development and implementation of preventive maintenance programs (e.g., prevent leakages; spray nozzle inspections, etc.).	x			
Installation of controls and process automation measures (e.g., installation of automatic shutoff nozzles and valves; installation of flow control valves to regulate water flows; use of automated CIP systems; high level alarms to prevent tank overflows; etc.).	x	x		
Perform water and energy efficiency audits (e.g., condensate recovery; optimize pump performance; heat recovery from hot streams; etc.).	x			
Urge establishments to obtain and follow international certifications in environmental/water management (e.g., ISO 46001 – Water Efficiency Management System; ISO14046 – Water Footprint, etc.).	x	x	x	x

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