Municipal Water Technologies Review of Recent Trends

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Developed with assistance from Chemonics Egypt's Review of Current Knowlwdge (ROCK) Team

Outline

1. The Global Water Situation
2. Water Treatment Technologies
3. Water Conservation in Industry
4. Future of Water Technology

1. The Global Water Situation

The Global Water Situation

The global situation

- Less than 3% of the world's water is fresh – the rest is seawater and undrinkable.
- Of this 3% over 2.5% is frozen, locked up in Antarctica, the Arctic and glaciers, and not available to man.
- Thus humanity must rely on this 0.5% for all of man's and ecosystem's fresh water needs.

Where is this 0.5 % of fresh water?[1,2]

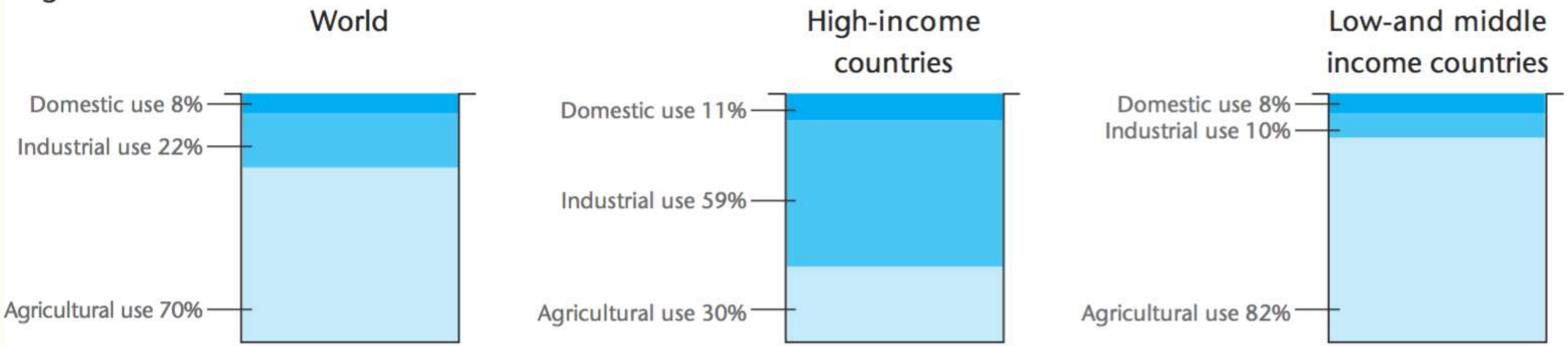
- 10,000,000 km^3 stored in underground aquifers.
  Since 1950 there has been a rapid expansion of groundwater exploitation providing:
  50% of all drinking water
  40% of industrial water
  20% of irrigation water.[3]
- 119,000 km^3 net of rainfall falling on land after accounting for evaporation.
- 91,000 km3 in natural lakes.
- Over 5,000 km^3 in man made storage facilities – reservoirs. There has been a 7 fold increase in global storage capacity since 1950.
- 2,120 km^3 in rivers – constantly replaced from rainfall and melting snow and ice.

Source: Reference 1

Who uses fresh water?

Competing water uses for main income groups of countries[6]

Industrial use of water increases with country income, going from 10% for low- and middle- income countries to 59% for high-income countries.



Ref. 6: "Water for People, Water for Life" United Nations World Water Development Report, UNESCO, 2003
www.unesdoc.unesco.org

Source: Reference 1

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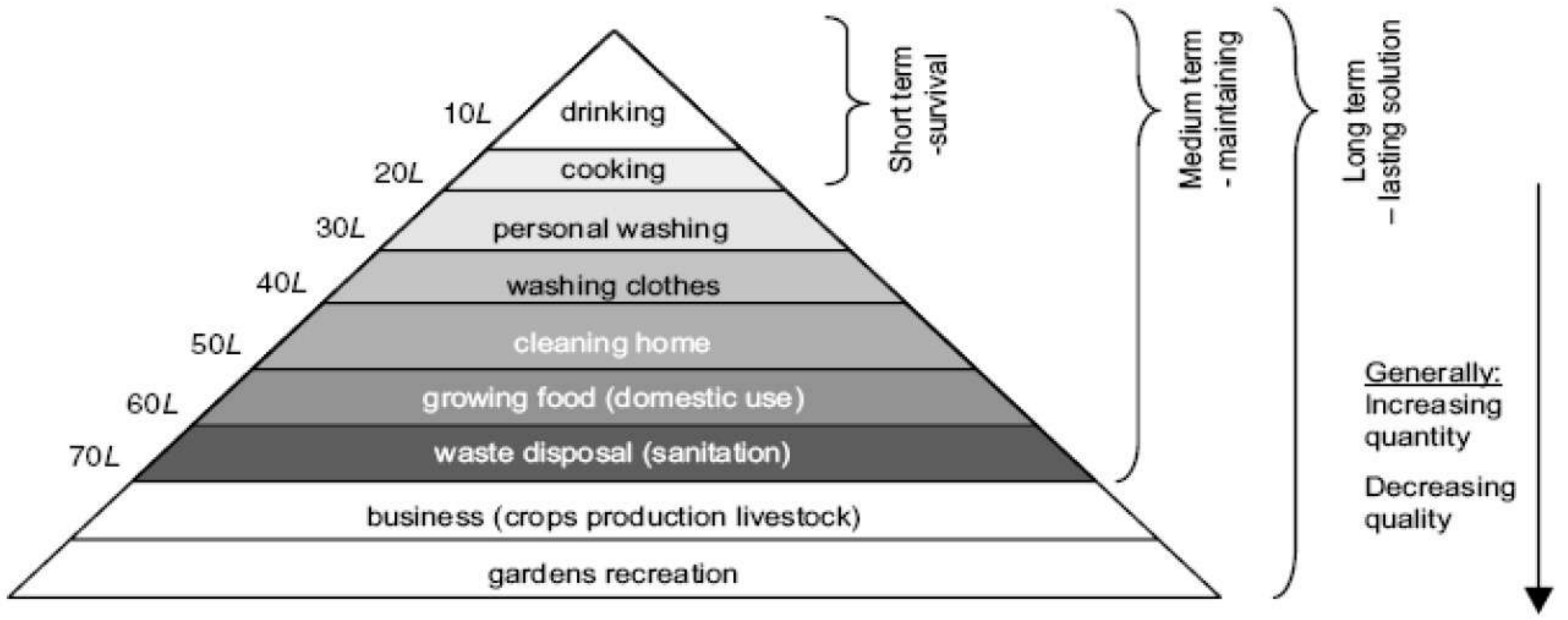
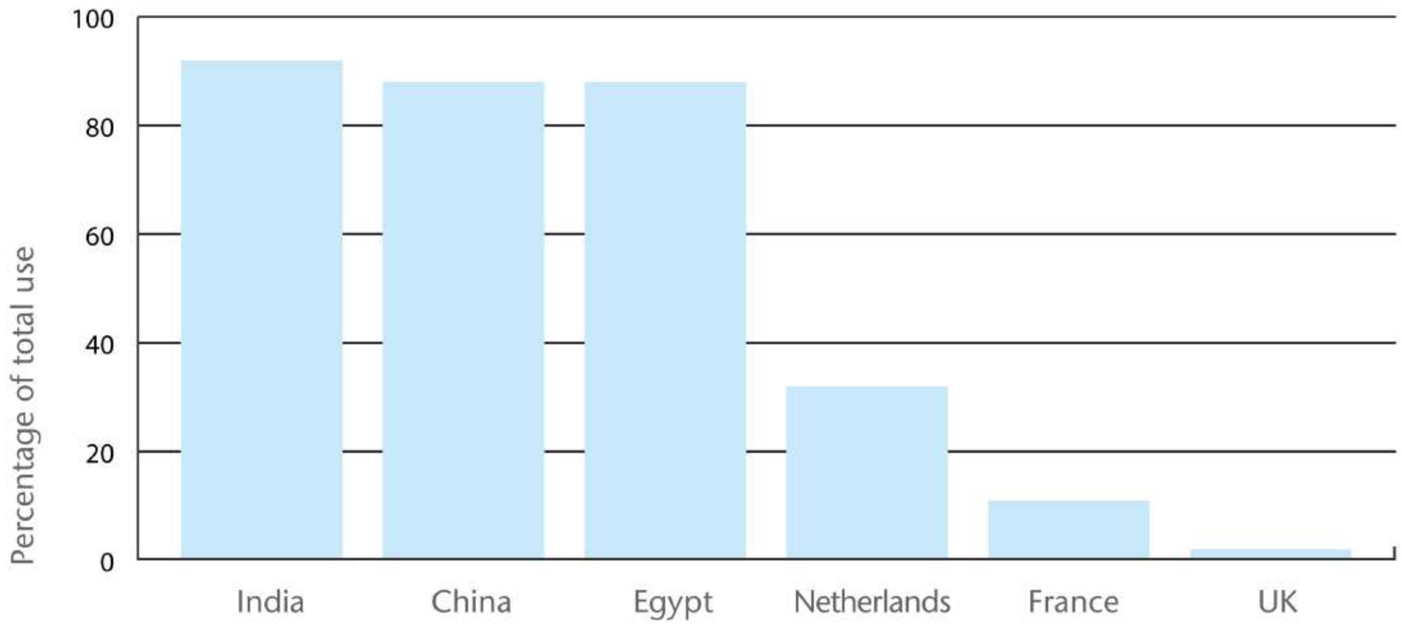


Figure 1. Hierarchy of water requirements
(after Abraham Maslow's (1908-1970) hierarchy of needs)

Agriculture

In many developing nations, irrigation accounts for over 90% of water withdrawn from available sources for use. In England where rain is abundant year round, water used for agriculture accounts for less than 1% of human usage. Yet even on the same continent, water used for irrigation in Spain, Portugal and Greece exceeds 70% of total usage. Irrigation has been a key component of the green revolution that has enabled many developing countries to produce enough food to feed everyone. More water will be needed to produce more food for 3 billion more people. But increasing competition for water and inefficient irrigation practices could constrain future food production.

Percentage of total water used for irrigation[8]



Ref. : "Global Water Crisis, the Major Issue of the 21st Century", Saeijs, H.F.L. & Van Berkel, M.J., European Water Pollution Control, 1995. Vol. 5.4 pp. 26-40; cited by Corporate Water Policies, Dec. 2003.

Source: Reference 1

Water in Industry

After agriculture, industry is the second largest user of water.
However the amount of water used varies widely from one type of industry to another.

[No water, no business]

Cooling water

The largest single use of water by industry is for cooling in thermal power generation.

Water as a medium for waste disposal

Many businesses dispose of wastewater or cleaning water into natural fresh water systems. Rivers and lakes can “process” small quantities of waste that can be broken down by nature. However, when these limits are exceeded, water quality declines and the downstream water is no longer useable without expensive treatment.

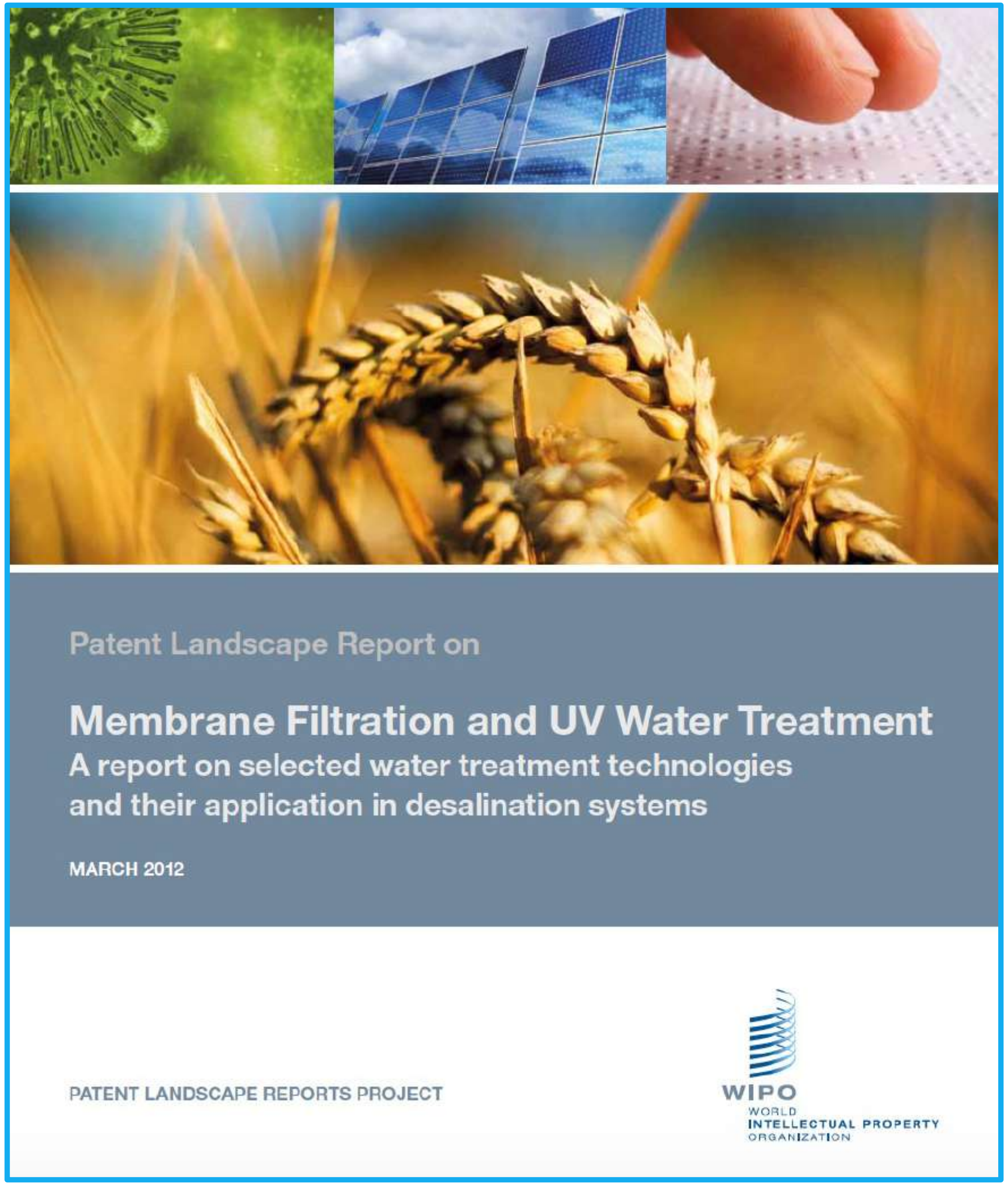
Source: Reference 1

2. Water Treatment Technologies

Water Treatment Technologies:

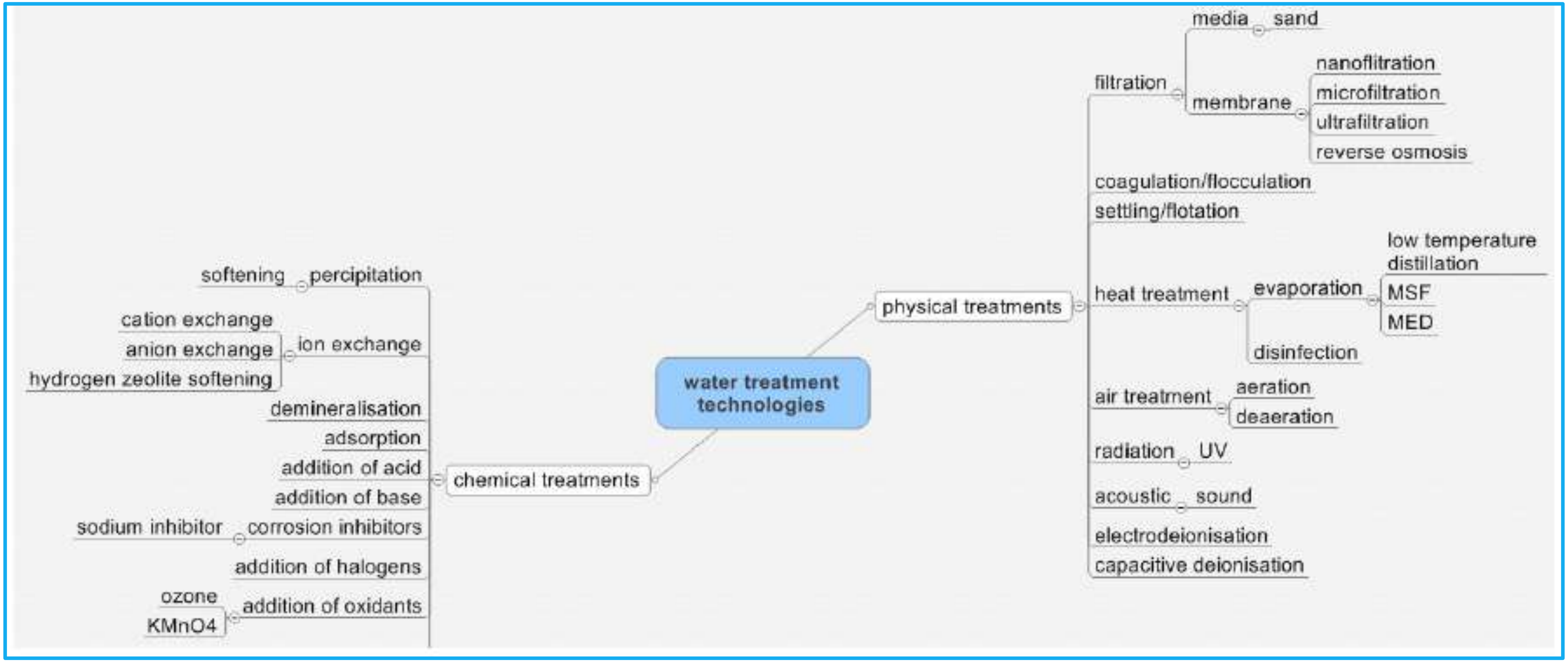
This report presents patent landscape of a specific type of water treatment technology, but I am using its introduction to present an overview of water treatment technology .

Patent landscape reports attempts to research and describe the patterns of patenting and innovation activity related to a specific technology field.

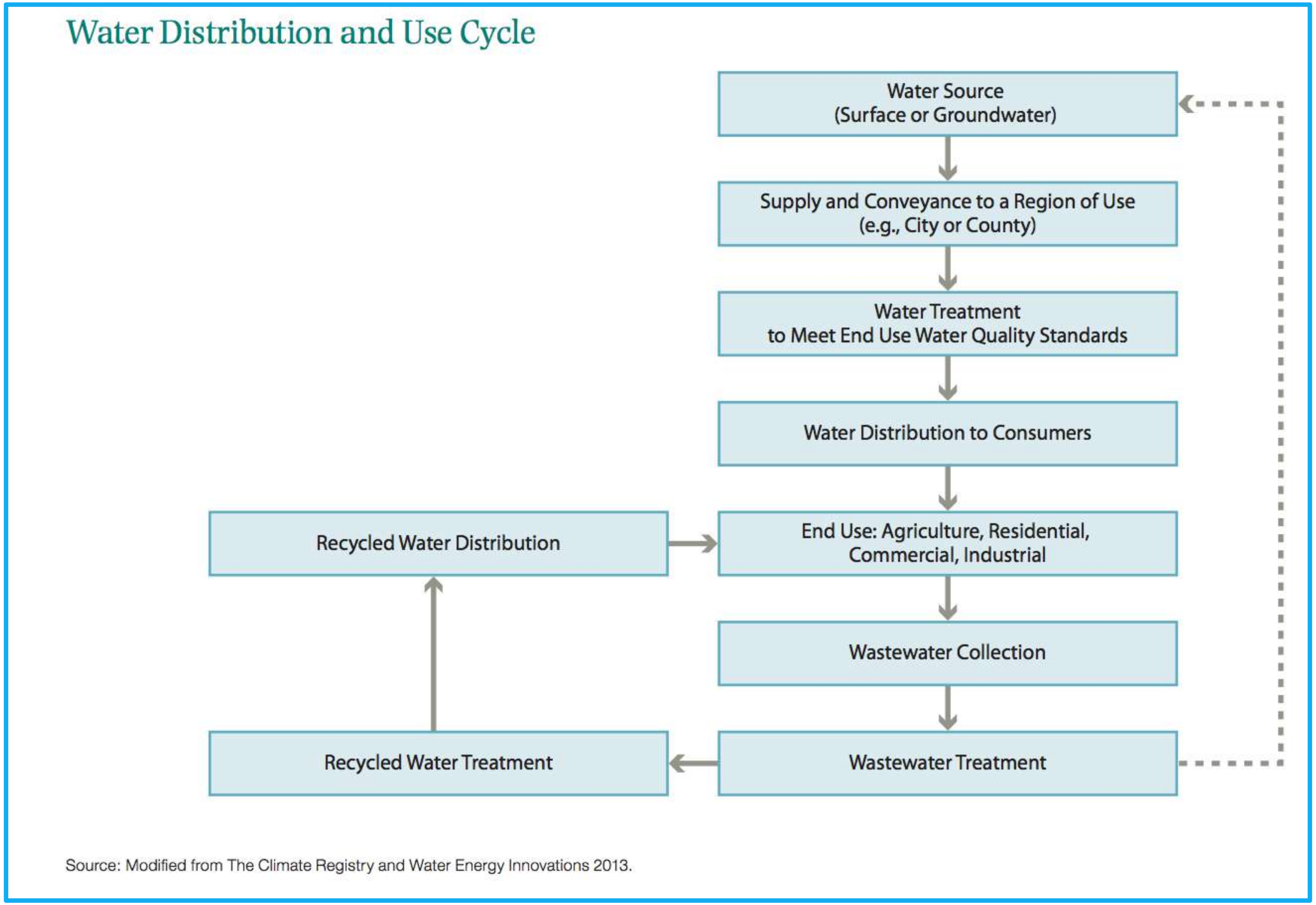


Water Treatment technologies:

The figure illustrates water treatment technologies for both physical and chemical treatment processes: it indicates the vast number of technology types used in water treatment.

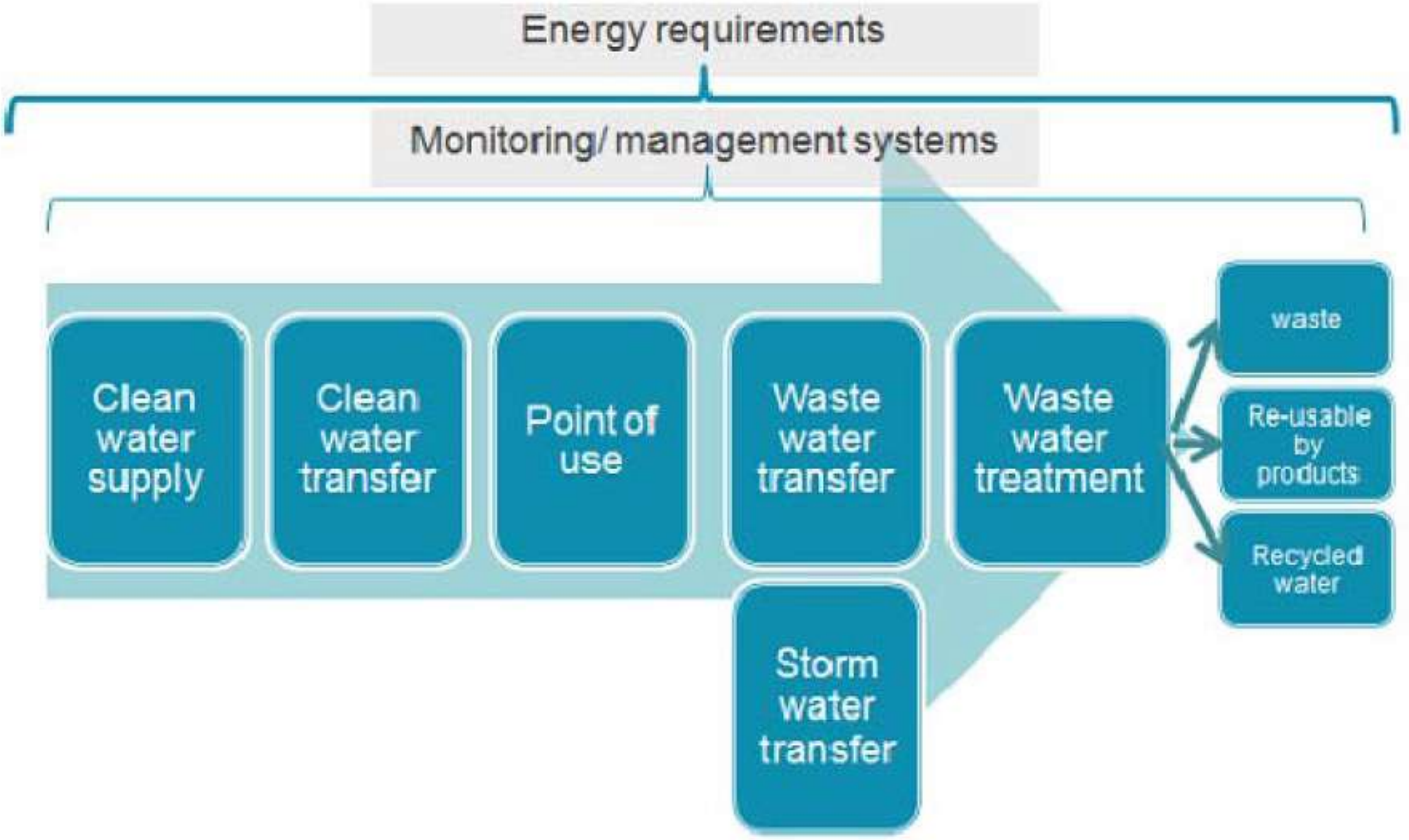


The figure shows the water cycle starting from “source”, all the way tel wastewater is treated and re-used



Water Treatment Technology Value Chain:

The figure illustrates key elements in the water treatment value chain.



Raw Water Constituents, Main Problems Associated and its Impacts

Suspended solids do not only cause water to have an unsightly appearance. It can also cause deposits to form in waterlines and the suspended solids interfere with most of the other water treatment processes.

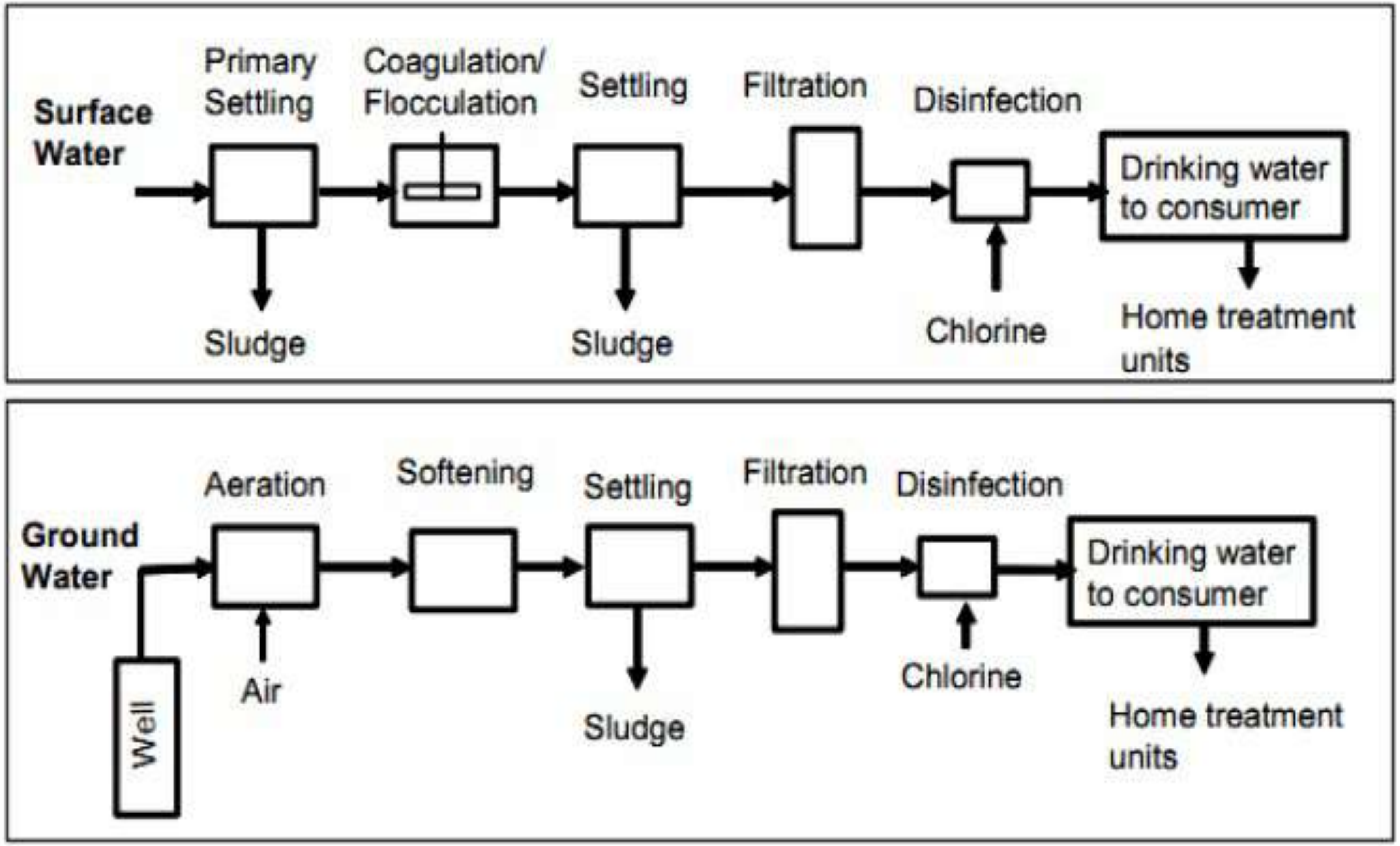
Dissolved solids can cause health concerns (such as excessive fluoride content in the water), and pose serious risks to the water treatment and transfer systems caused by deposition and corrosive actions (such as hardness and pH). Hardness of the feedwater can cause scaling in the system - closely related to the water alkalinity. Alkalinity as well as free mineral acids and carbon dioxide, can have corrosive effects on different parts of the system. A variety of other chemicals dissolved in the feedwater can also cause scaling, corrosion and other deposits in the system. These chemicals include sulphate, chloride, nitrate, sodium, silica, iron, manganese, aluminium, oxygen, hydrogen sulphide and ammonia. These issues can be addressed by a number of physical and chemical treatment processes.

Micro organisms such as bacteria, viruses and protozoa present in the water can cause health problems. These can be removed by disinfection processes such as chlorination, UV irradiation or heat treatment.

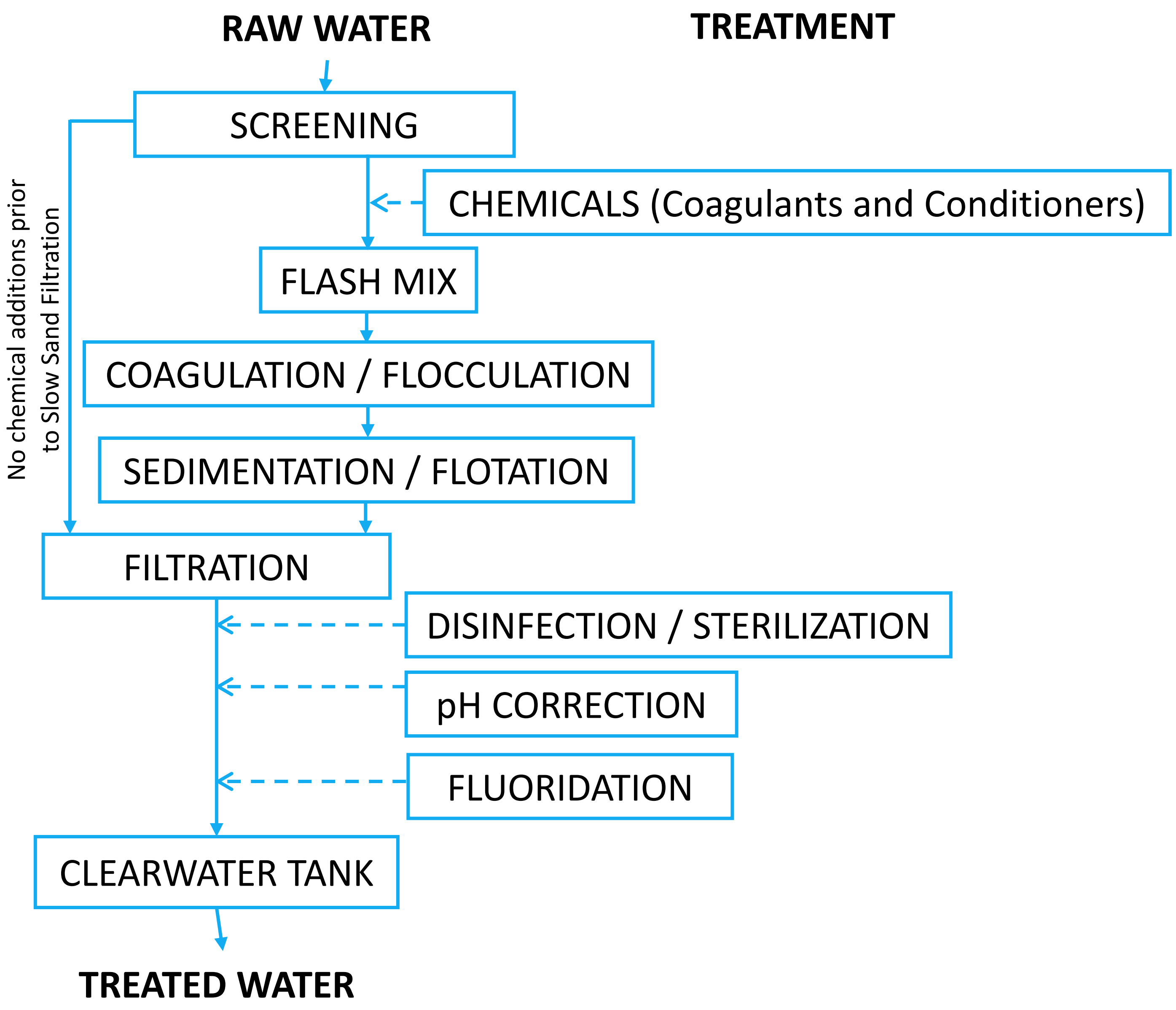
The table shows main problems associated with untreated feed water and their causes.

	Deposits	Scaling	Corrosion	Embrittlement	Health Concerns	Smell
Suspended Solids	✓					✓
Dissolved Solids	✓	✓	✓	✓	✓	✓
Micro organisms	✓				✓	✓

Difference in Water Treatment Train between Surface Water and Ground Water



Typical Water Treatment Plant Block Flow Diagram



EFFECT ON WATER

Excludes fish and removes leaves, sticks and other large debris.

Breaks down colloidal stability. Adjusts pH for optimum coagulation.

Mixes chemicals with raw water, containing fine particles that will not readily settle or filter out of the water.

Gathers together fine, light particles to form larger clumps (floc) to aid the sedimentation/flotation and filtration processes.

Sedimentation settles out large suspended particles. Flotation floats out the particles with dissolved air.

Rapid gravity filtration filters or removes remaining suspended particles.

Slow sand filtration also involves biological action.

Kills / inactivates disease-causing organisms. Provides chlorine residual for distribution system, where chlorine is used.

Helps control corrosive properties of water.

Helps control dental caries in children and young adults.

Stores water prior to discharge to service reservoirs.

Basic Unit Operations as applied in Water Treatment Technologies and its function in dealing with main raw water constituents.

Technologies		Suspended Solids	Dissolved Solids	Disinfection
Physical Treatment	Coagulation	✓	✓	
	Settling/Flotation	✓		
	Filtration (Media or membrane)	✓	✓	✓
	Electrodialysis		✓	
	Heat Treatment		✓	✓
	Aeration/ deaeration		✓	
	Radiation (UV)			✓
	Acoustic			✓
Chemical Treatment	Precipitation		✓	
	Ion exchange		✓	
	Demineralization		✓	
	Adsorption		✓	
	Addition of acid		✓	✓
	Addition of Alkaline		✓	✓
	Corrosion inhibitors		✓	
	Chlorination		✓	✓
	Halogens			✓
	Metals			✓

Overview or the removal capacity and effectiveness of several water treatment systems

	Bacteria	Cysts	Viruses	Algae	Coarse particle	Turbidity	Colour	Al*	As*	Fe*/ Mn*	NO3*	Pesticides	Solvents	Taste/ Colour
Coagulation/ flocculation 1	+	+	+	+	++	++	++	++	+	++				
Sedimentation					++	+		+		+				
Gravel filter/screen				+	++	+		+		+				
Rapid sand filtration	+	+	+	+	++	+		+		+				
Slow sand filtration	++	++	++	++	++	++		+		+				
Chlorination	++		++	+			+							
Ozonation	++	+	++	++			+					++		++
UV	++	+	++	+										
Activated carbon							+					+	+	++
Activated alumina									++					
Ceramic filter	++	++		++	++	++								
Ion exchange								+	+	++	++			
Membranes	++	++	++	++	++	++	++	++	+	++	++	++		++

*Al: aluminium, As: arsenic, Fe: iron and Mn: manganese , NO_3: Nitrate

\+ Partly effective ++ Effective/ preferred technique

[1] Pre--Oxidation may be required for effective removal of aluminium, arsenic, iron and manganese

Source: Manual on Treatment for Small Water Supply Systems; *http://dwi.defra.gov.uk/research/completed-research/reports/DWI70_2_137_manual.pdf*

Filtration

Filtration is the process of passing water through material to remove particulate and other impurities, including floc, from the water being treated. These impurities consist of suspended particles (fine silts and clays), biological matter (bacteria, plankton, spores, cysts or other matter) and floc. The material used in filters for public water supply is normally a bed of sand, coal, or other granular substance. Filtration processes can generally be classified as being either slow or rapid.

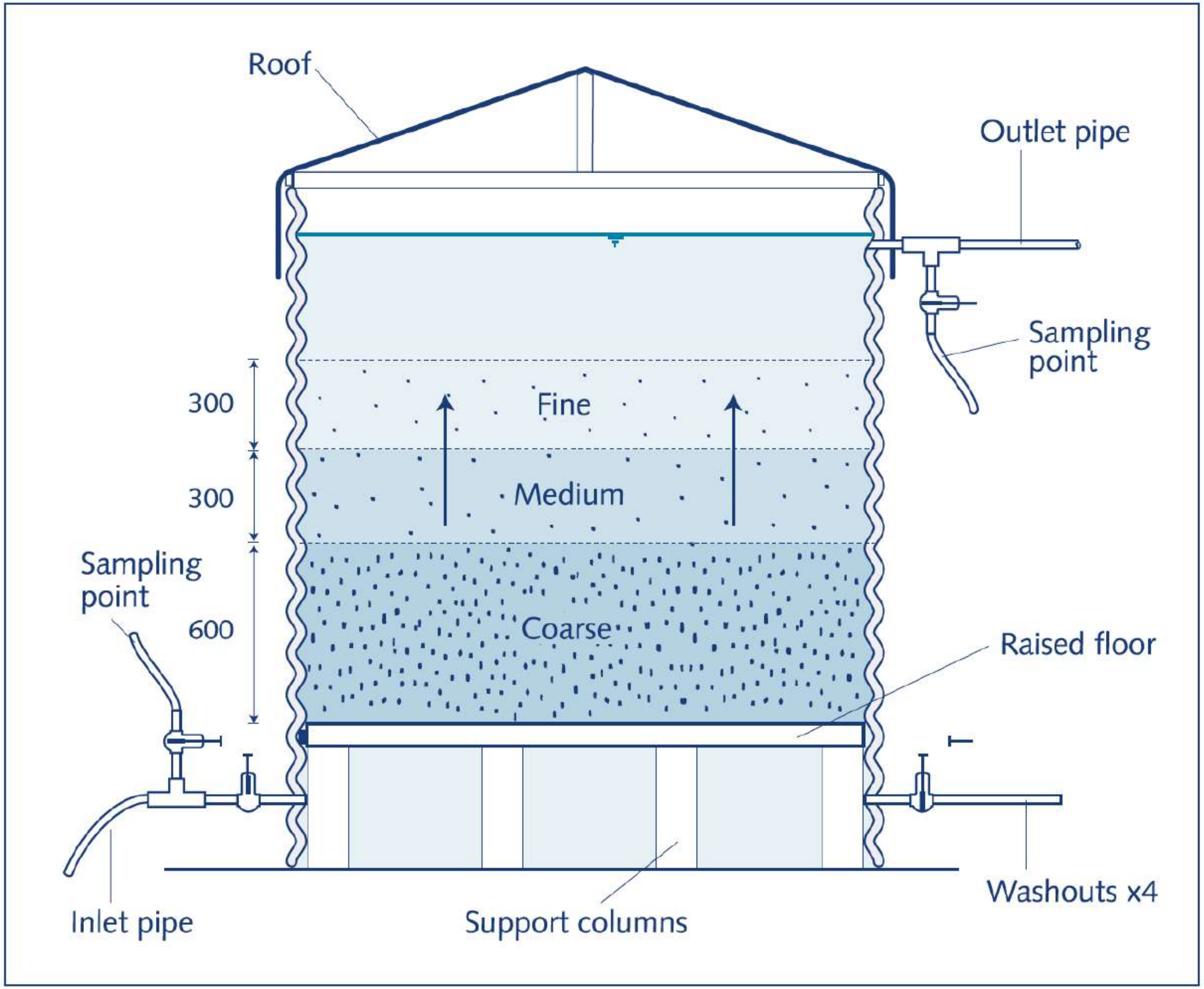
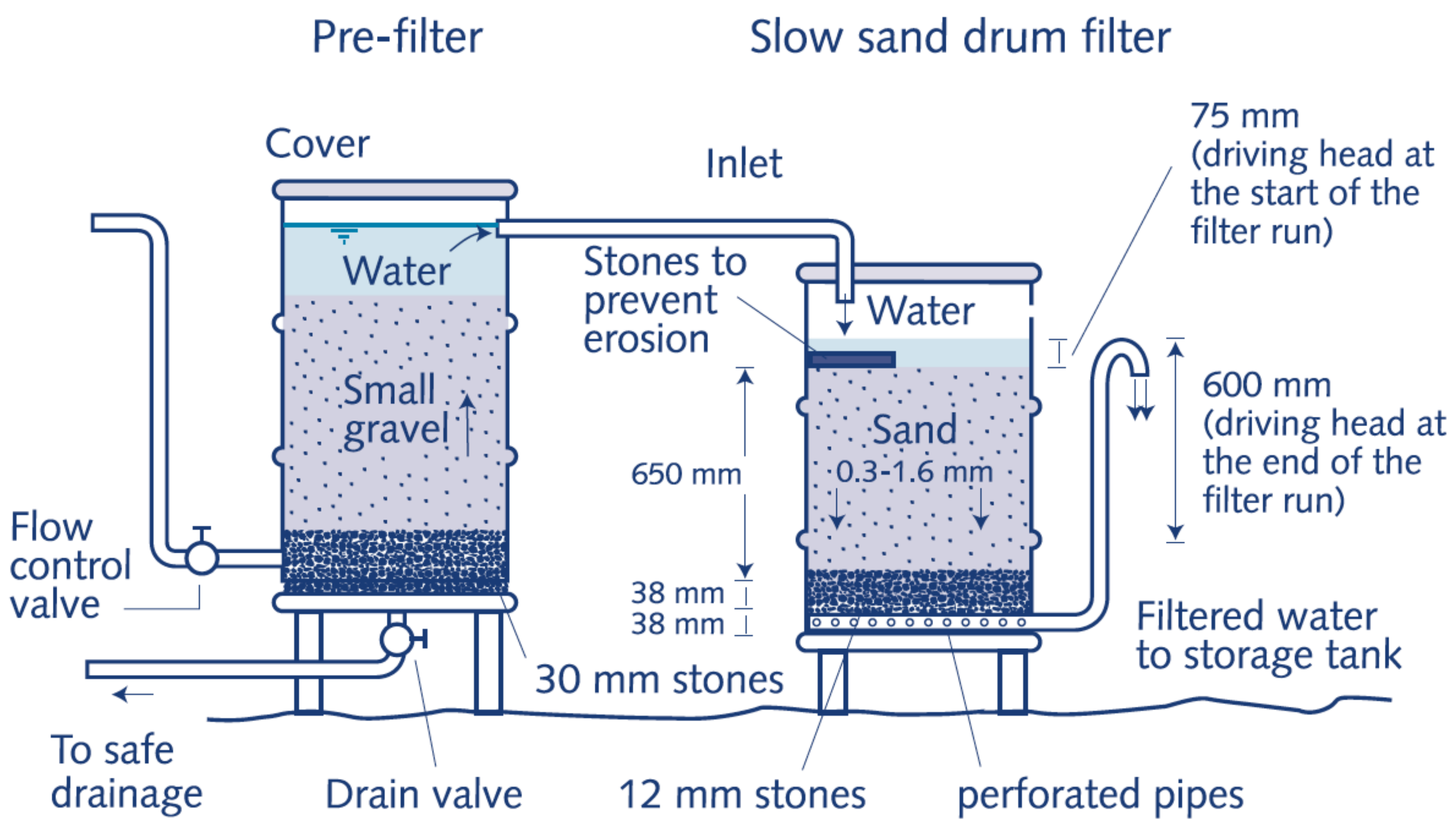


Figure 24.7. A vertical flow roughing filter (Source: Oxfam, 2000)
(Adapted from: Davis and Lambert, 2002)



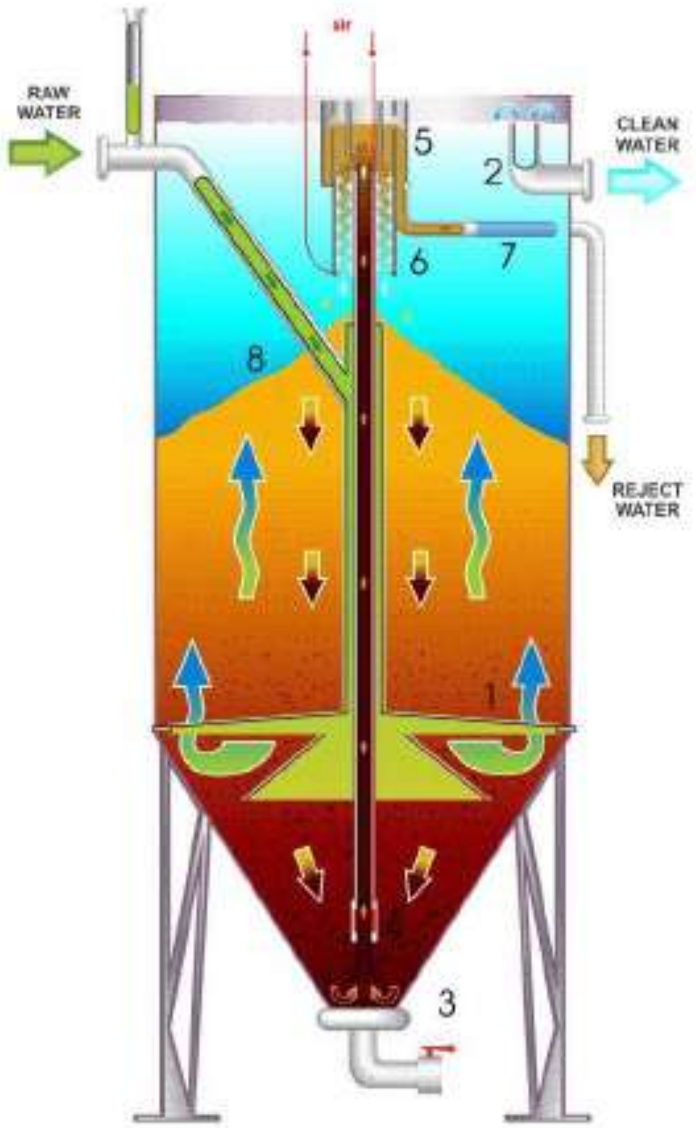
Pre-filter
Slow sand drum filter
Cover
Inlet
75 mm
(driving head at
the start of the
filter run)
Water
Stones to
prevent
erosion
Water
Small
gravel
650 mm
Sand
0.3-1.6 mm
600 mm
(driving head at
the end of the
filter run)
Flow
control
valve
38 mm
38 mm
Filtered water
to storage tank
30 mm stones
To safe
drainage
Drain valve
12 mm stones
perforated pipes

Innovative Continuous filter design

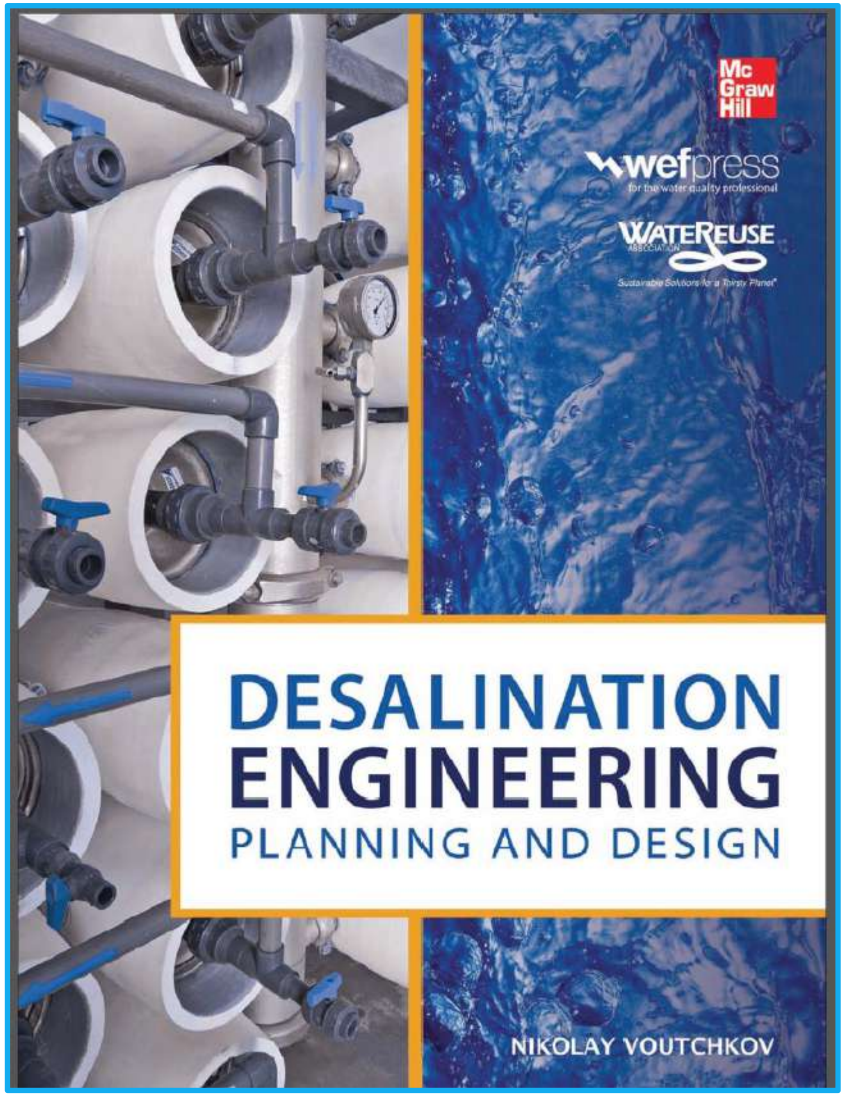
This DYNAMIK sand filter is continuous (no backwash) that can achieve high standard of drinking water. It is simple and compact design with no moving parts.

OPERATION

The principle of operation of the self-flushing sand filter consists in the counter-current filtration. Raw water, which enters the filter via inlet connection at its top is evenly distributed within the filtration bed by a distributor (1) and filtered during its upflow through the sand bed. Clean filtrate is discharged via upper outlet (2). The mammoth pump (4) lifts contaminated slurry from the filter bottom (3) to a hydropneumatic gritwasher (5). Taking the advantage of the difference in water table levels between the filter and hydropneumatic grit washer, the grit backwash process using the clean filtrate flowing into the flushing labyrinth at its bottom is continuously taking place concurrently with water filtration. While the separation of the sand grains in the turbulent slurry starts already in its upward movement in the mammoth pump, the proper backwashing takes place in the flushing labyrinth (6). The reject water is removed by the reject water pipe (7) to the outside, while the clean sand falls down to the filtration sand bed (8). As a result, there is a continuous downward circulation of the filtration bed with the concurrent self-correcting processes of the water treatment and sand backwashing.



Desalination: Main References used to prepare the presentation

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WATER RESEARCH

Review

State of the art and review on the treatment technologies of water reverse osmosis concentrates

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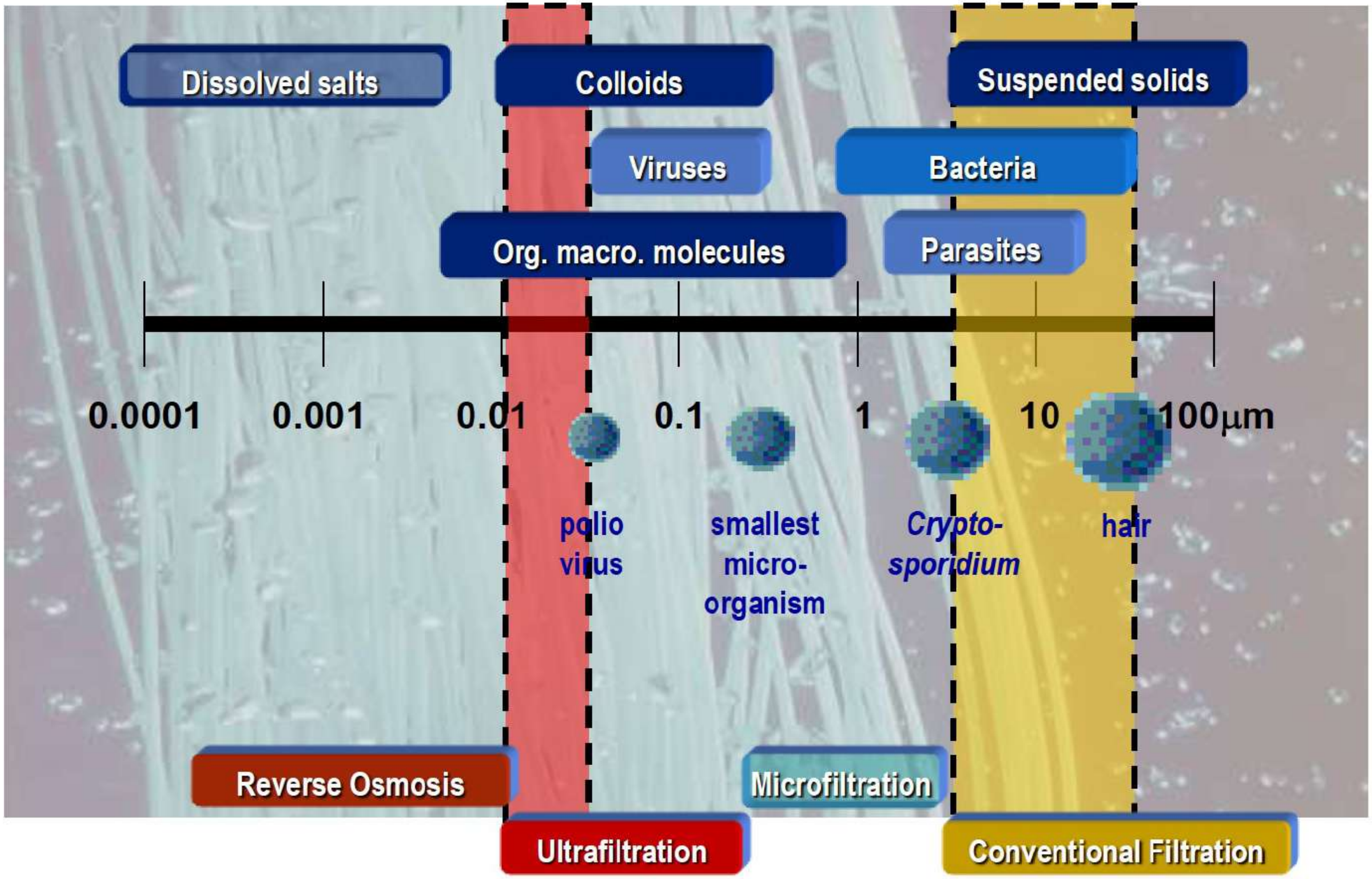
Effectiveness of different filtration processes in liquid-solid separation

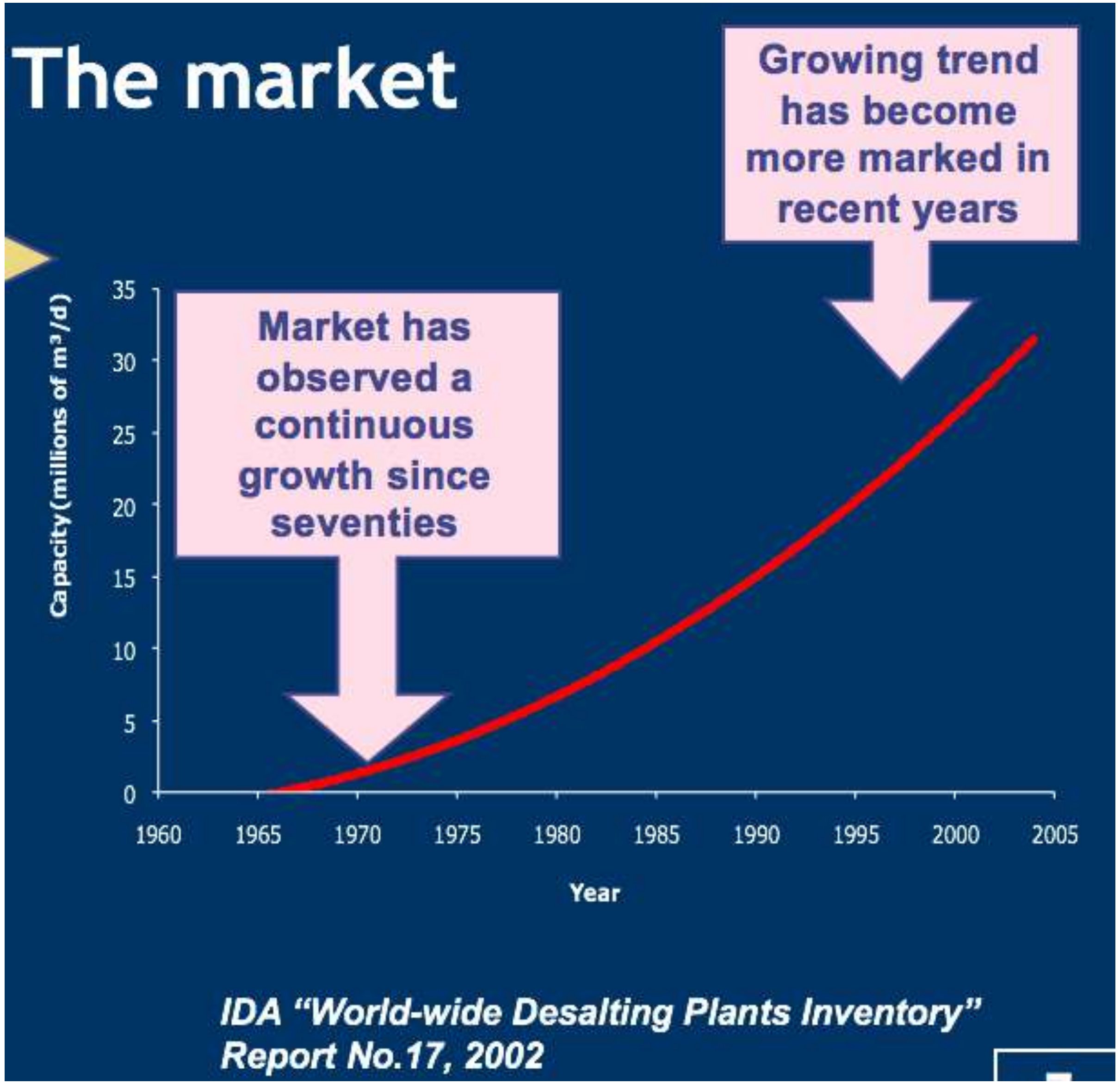


Desalination Market

Currently about 15,000 desalination units are operating world-wide with a total capacity of over 32 millions m³/d

Expected trend

The desalination capacity contracted annually on average is 1 million m³/d which is equivalent to some $ 2,000 millions



Desalination Technologies

Distillation processes

Liquid to vapour passage
(Thermal process)

Drinking water is generated by evaporation and successive condensation of the feed water

- ⇒ multi-stage flash (MSF)
- ⇒ multiple effect evaporation (MEE)
- ⇒ mechanical vapor compression (MVC)

Membrane processes

No phase change
(Membrane technologies)

Drinking water is generated by separation of salt from the feed water due to the passage through specific membranes

- ⇒ reverse osmosis (RO)
- ⇒ electrodialysis (ED)

Market Share

⇒ Over 65% of all applications concerns seawater desalination

⇒ MSF and RO cover together almost the 90% of market whether considering all applications or seawater only

⇒ ED is significant only for brackish water desalination due to its technological constraints

⇒ Analogous reasons limits the application of RO for seawater desalination

⇒ MEE and MVC are applied on a minor scale mainly for seawater desalination

Desalination Barriers

⇒ Brackish or seawater must be easily accessible

⇒ Advanced processes need a considerable know-how

⇒ Construction and running of the plant have a significant impact on the environment

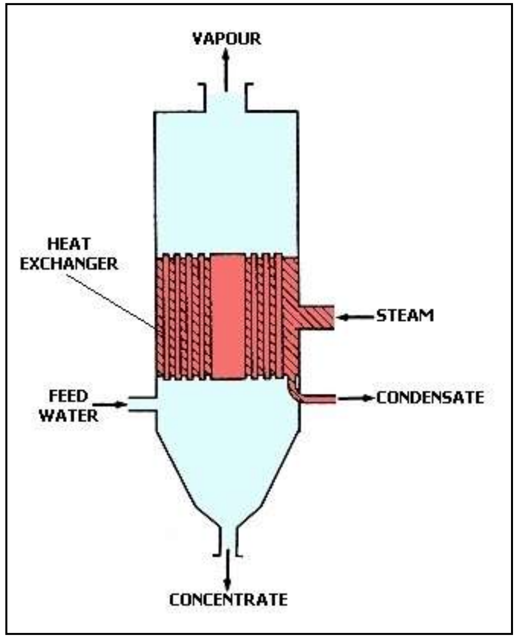
⇒ A vast initial investment is required

⇒ Water production cost is markedly higher than traditional provisioning value in ordinary conditions

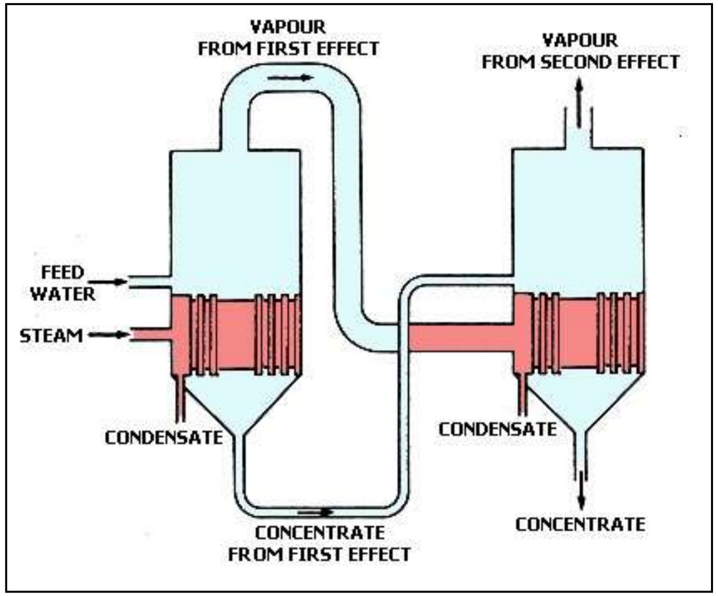
⇒ Energy must be available in large amounts and at a reasonable price

Thermal Desalination

A single-effect evaporator is essentially a heat exchanger in which feed seawater is boiled to give a vapour almost devoid of salt. Required heat is supplied by the condensation of the motive steam



The low pressure steam generated by the evaporator can be used for further heating in a following effect



The evaporation in the second effect via the steam provided by the first one requires a lower boiling temperature and hence a minor pressure, so the feed water evaporates in a minor part also by flashing

Thermal Desalination: Recent Trends and Research Topics

Recent Trends

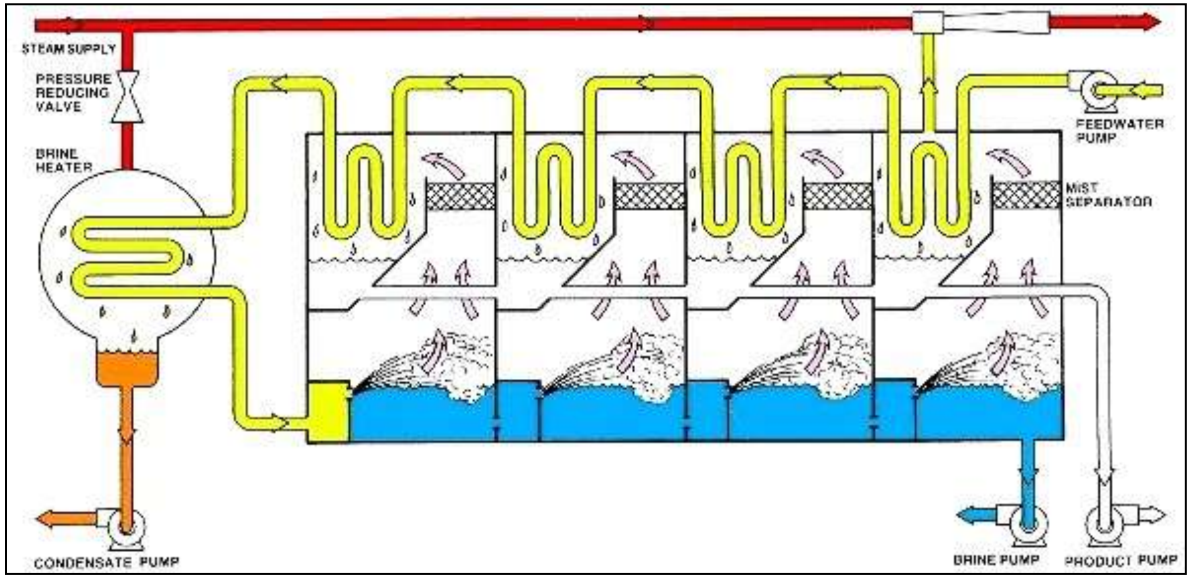
- increase in the unit capacity, by prevailing over technological barriers, such like pumps size limitations, tubes materials and dimensions thus obtaining better process economics
- high corrosion resistance materials for evaporators, such like titanium and aluminum brass, replacing traditional copper/nickel and stainless and carbon steel

Research Topics

- combination with absorption or adsorption heat pumps to boost the gain output ratio
- development of solutions, such like hybrid nanofiltration/MEE system, antiscalant materials, for operating at higher temperature
- reducing the number of pumps, main causes of electric power consumption
- plastic construction materials, with advantages related to cost, lightness, resistance to chemical attack and mechanical erosion, machining, LCA

Multiple Effect Flash Evaporation: Process Description

1. Feed seawater is warmed up by the motive steam in the "brine heater", then flows through several chambers, where the ambient pressure is so low that it immediately starts to boil, almost "flashing" into steam
2. Generally, only a small percentage of water is converted to steam in a single stage, depending on the pressure, since evaporation will continue only until the water cools down to the boiling point
3. The steam generated by flashing is condensed and thus converted to fresh water through the heat exchange with the incoming feed water going to the brine heater which is consequently pre-heated



- ✓ Vapour Compression is a thermal process where the heat required to evaporate the seawater comes from the compression of vapour instead of the direct exchange with the motive steam
- ✓ Two primary devices are used to boost the vapour pressure and temperature so as to generate the heat: a mechanical compressor or a steam ejector

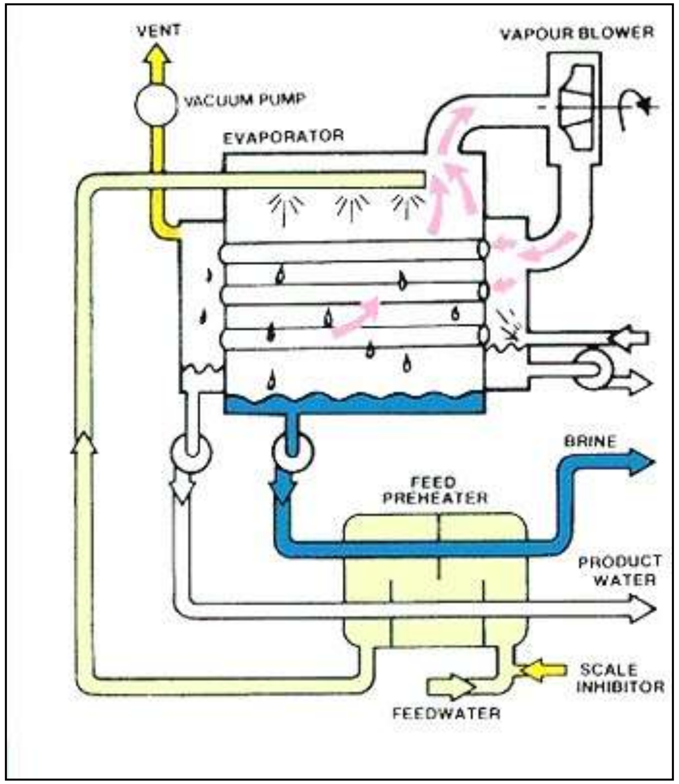
The mechanical compressor is usually electrically driven, thus enabling the sole use of electrical power to produce water by distillation

<u>In a simplified method for MVC:</u>

⇒ the compressor aspirates the vapour from the vessel, compresses and condenses it inside a tube bundle in the same stage

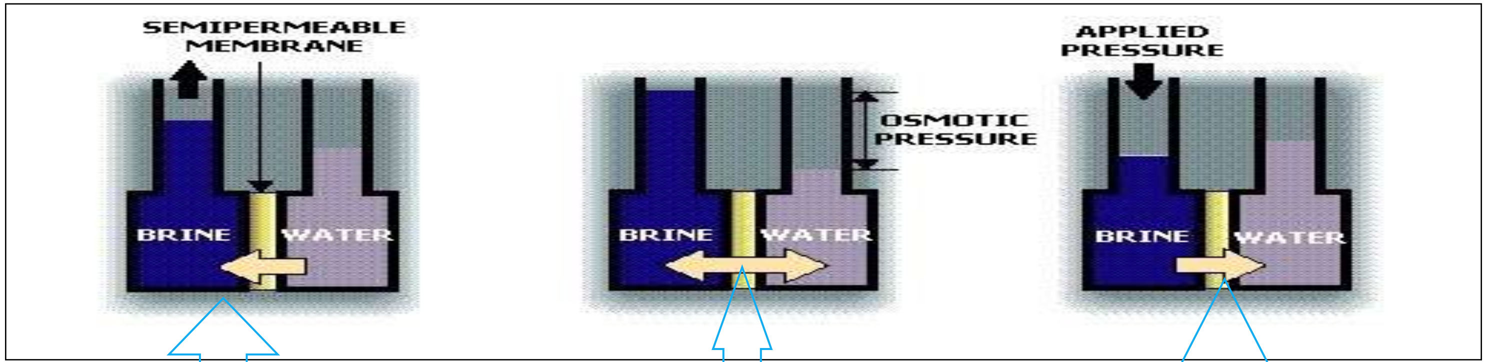
⇒ seawater is sprayed on the outside of the tubes at the point where it boils and partially evaporates

⇒ vapour is condensed via the heat exchange with the incoming feed water which is consequently pre-heated



Reverse Osmosis (RO) Desalination: principle of Operation

RO is a pressure-driven process that separates two solutions with differing concentrations across a semi-permeable membrane. The major energy requirement for this system is for the pressurization of the feed water. The RO system uses a fine membrane that allows pure water to pass through while rejecting the large salt molecules. This is achieved by pressurizing the seawater to about 60 bars and then to force the water through the mechanical constriction presented by the membrane against the natural osmotic pressure. RO has a number of advantages over distillation. Ease of operation and energy efficiency are two major considerations. A RO plant typically uses one-third less energy than distillation.



OSMOSIS

Water flows from lower to higher salt concentration

EQUILIBRIUM

Pressure required to stop water flow reaching equil. is defined as *osmotic pressure*

REVERSE OSMOSIS

Flow is reversed from higher to lower salt concentration by applying a pressure adequately greater than osmotic pressure

RO Recent Trends and Research Topics

Recent Trends

- continuous increase in the total plant capacity, by augmenting the number of vessels per bank and the number of parallel banks, to meet larger demands with economies of scale
- development of a new generation of membranes having higher salt rejection, recovery rate, mechanical strength, and chemical resistance

Research Topics

- innovative composite materials for the achievement of low fouling membranes
- on line regenerating membranes for the pretreatment of raw water
- advanced energy recovery devices matching high efficiency and low cost

Location: Al Jubail (Saudi Arabia)

Capacity: 90,920 m³/d

Layout: 15 parallel trains of 205 modules each

Design:

- single pass
- hollow fiber membranes
- energy recovery: Francis Turbine

Operational parameters:

- φ = 35%
- p_{max} = 82 bar
- T = 25 °C
- TDS< 450 mg/l
- Cl^{-}< 250 mg/l

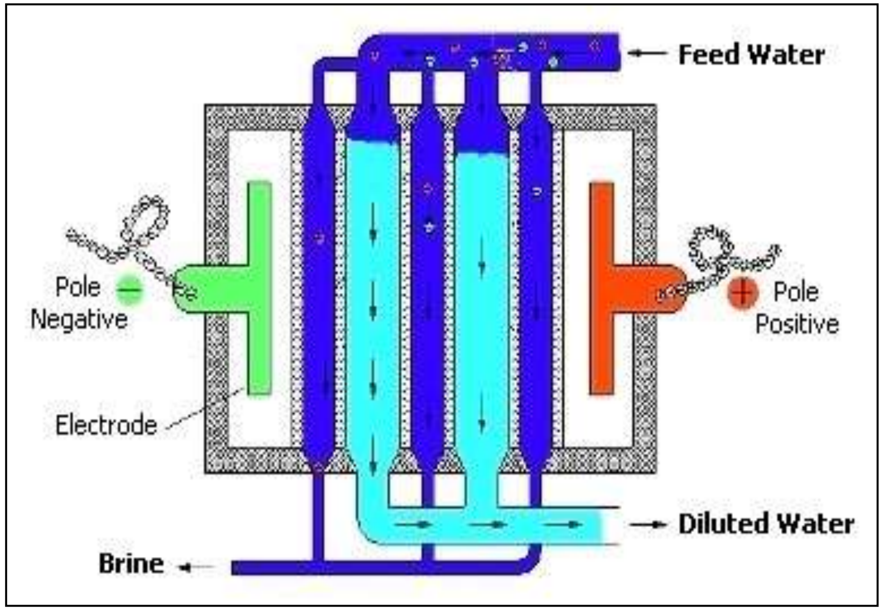
Specific energy consumption:

5 kWh/m³

Desalination: Electro-Dialysis principle of operation

1. The dissolved ionic constituents in a saline solution (Na^+, Cl^-, Ca^{++}, CO_3^{--}) are dispersed in water, effectively neutralising their individual charges
2. When electric current is carried through the solution by means of a source of direct current, the ions tend to migrate to the electrode with the opposite charge
3. Water desalination is obtained by placement of membranes between a pair of electrodes that will allow either cations or anions (but not both) to pass

- Membranes are arranged alternatively (anion-selective followed by cation-selective) so as to create concentrated and diluted solutions in the spaces between (cells)
- A cell pair consists of the dilute cell from which the ions migrate and the concentrate cell in which the ions are trapped



Comparison between MSF and RO Desalination Systems

Multi-Stage Flash

ADVANTAGES

- ✓ reliable, robust process
- ✓ more than 30 years of experience
- ✓ not sensitive to feed water quality
- ✓ long service life time
- ✓ significant cost savings due to the possible manufacturing in the client country

DISADVANTAGES

- ✓ higher specific investment cost
- ✓ higher specific exergy consumption
- ✓ limited to high capacities

Reverse Osmosis

ADVANTAGES

- ✓ lower specific investment cost
- ✓ lower specific exergy consumption
- ✓ any capacity possible

DISADVANTAGES

- ✓ sensitive to feed water quality, danger of biofouling
- ✓ strong dependence on membrane/module manufacturer
- ✓ highly qualified manpower needed for operation and maintenance
- ✓ high consumption of chemicals

Solar Desalinations

POSSIBLE BENEFITS

- countries with fresh water shortage can generally rely on high values of solar irradiance
- solar energy availability is maximum in the hot season when fresh water demand increases and resources are reduced
- water constitutes a medium which allows to store for a long time possible energy surplus, economically and without significant losses
- lack of water usually takes place in isolated areas, like rural regions or small islands, where the soil occupation is not critical and the cost of traditional means of supply may dramatically rise

ADDITIONAL REMARKS FOR SMALL SCALE APPLICATIONS

Capacity up to 1,000 m^3/d [domestic water needs of a community of more than 5,000 people]

- ✓ **low capital cost**
- ✓ **reduced construction time**
- ✓ **utilisation of local manpower and materials**
- ✓ **simple management**

Integration Among Different Options

COUPLING OPTIONS

In general solar energy can feed any desalination process

SOLAR TECHNOLOGY	DESALINATION PROCESS: MSF	MEE	MVC	RO
Concentrating Parabolic Collectors (Solar thermoelectric station producing both electricity and eventually heat through a cogeneration arrangement)	●	●	●	●
Flat Plate/Evacuated Tubular Collectors	●	●		
Salt Gradient Solar Pond	●	●		
Photovoltaic			●	●

Options

MEE driven by low temperature solar thermal collectors, both flat plate and evacuated tubular

Systems for the generation of high temperature heat (linear parabolic collectors, solar towers)

Alternative systems

- ⇒ RO coupled with photovoltaic panels
- ⇒ MEE coupled with salt gradient solar pond

- ⇒ larger capacities are requested
- ⇒ a combined demand of power must be present
- ⇒ economic feasibility is still too far

Coupling Options

RO COUPLED WITH PHOTOVOLTAIC	
ADVANTAGES	**DRAWBACKS**
✓ lowest specific soil occupation ✓ ideal for stand-alone configuration ✓ any capacity possible with no dramatic rise in cost ✓ best potential towards further cost reduction	✓ sensitive to feed water quality ✓ advanced materials required ✓ complexity of design and management ✓ most costly operation due to membrane and battery replacement

MEE COUPLED WITH SALT GRADIENT SOLAR POND	
ADVANTAGES	**DRAWBACKS**
✓ competitive water production cost ✓ lowest investment ✓ simplified operation due to limited piping and absence of coverings ✓ use of discharged brine for salt gradient preservation	✓ availability of a huge area ✓ adequate mechanical and thermal characteristics of the ground ✓ long time for design, simulation, construction and fully operating ✓ difficulty in reliable predictions

Comparisons Among Options

CONVENTIONAL

- reference value for the water production cost can be assumed equal to 1 $/m^3$ in case of medium to small size desalination processes connected to the electric grid
- desalination system typically used in stand-alone configuration is a reverse osmosis process coupled with a diesel powered generator; due to the additional charges for transporting and fuel storage, water production cost can rise up to 1.5 $/m^3$

SOLAR

RO/PV

⇒ Specific capital cost	4,200 $/(m^3/d)$
⇒ Water production cost	2 $/m^3$
⇒ Specific area	10 $m^2/(m^3/d)$

MEE/SGSP

⇒ Specific area	70 $m^2/(m^3/d)$
⇒ Specific capital cost	3,700 $/(m^3/d)$
⇒ Water production cost	1.5 $/m^3$

Comparison summary table among selected desalination technologies

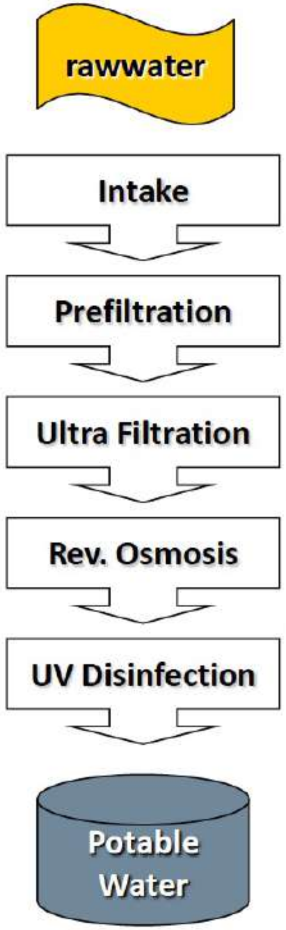
Overview of technical metrics and potential for technological advances for selected desalination technologies. (Source: Department of Energy, 2015)				
Technology	**Current Operating Temperature Range**	**Current Power Consumption**	**Current State of the Art Costs**	**Potential 'Game-Changing' Technology Advances**
Reverse Osmosis (RO)	ambient	~3 kWh/m^3	\$2.00/m^3	• Long-lifetime membranes (high-durability, low-fouling) • Integration with renewable primary energy sources
Multi-effect Distillation / Multi-stage Flash Distillation (MED/MSF)	70 – 110 °C	• 15 – 20 kWh$_t$/m^3 • 1 – 2kWh$_e$ additional	\$2 – \$3/m^3	• Low-cost, high-flux heat exchanger materials • Integration with waste/renewable sources of heat
Forward Osmosis (FO)	• Thermal FO: 80 – 100 °C • Non-thermally-driven FO is also being explored	• 0.5 – 1.5 kWh$_e$/m^3 • Thermal FO: additional 10 – 16 kWh$_t$/m^3	No commer-cial data	• New membranes designed for FO (currently using RO membranes) • Materials discovery for draw solutes
Membrane Distillation (MD)	40 – 100 °C	• 1 – 30 kWh$_t$/m^3 • Current wide range due to no large-scale projects	No current commercial data	• Thermally insulating membranes that preserve selectivity • Low-cost, high-flux heat exchanger materials
Dewvapora-tion	120 °C	6 kWh$_e$/m^3 – 407 kWh$_t$/m^3	\$80/m^3	• Low-cost, high-flux heat exchanger materials • Integration with waste/renewable sources of heat • Optimized system configuration
Capacitive Deionization	ambient	0.11kWh$_e$/m^3	No current commercial data	• Hybridization with other desal technologies • Novel electrode materials

Applying RO technology in the development of Emergency water treatment units

MEMBRANE FILTRATION & REVERSE OSMOSIS

Hydrocompact EMU 025 & 050

Mobile Emergency WT Unit



- NOT Sensitive to changing rawwater condition
- FULL removal of oil, organics, pesticides
- SALINITY removal up to 5.000 ppm
- GOOD process control
- GOOD established technology
- REDUCED chemical demand
- UV disinfection
- Setup and startup in FEW HOURS
- SUITABLE for longterm storage
- Conservation of membranes needed

Ovivo, 2012

Solar Pumping

Examples from India for groundwater and surface water pumping using solar energy

Photovoltaic Reverse Osmosis

Desalination and Water Treatment
www.deswater.com
31 (2011) 24–34
July
1944-3994 / 1944-3986
doi: 10.5004/dwt.2011.2398

Photovoltaic reverse osmosis —
Feasibility and a pathway to develop technology

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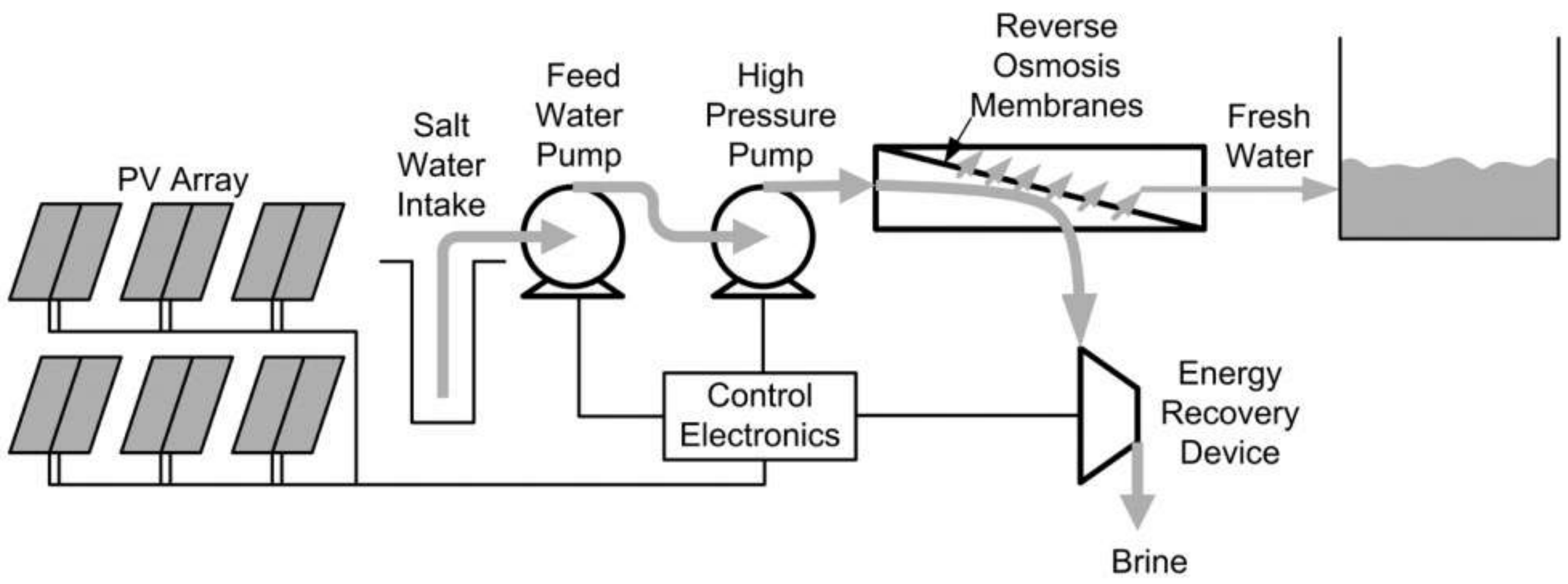
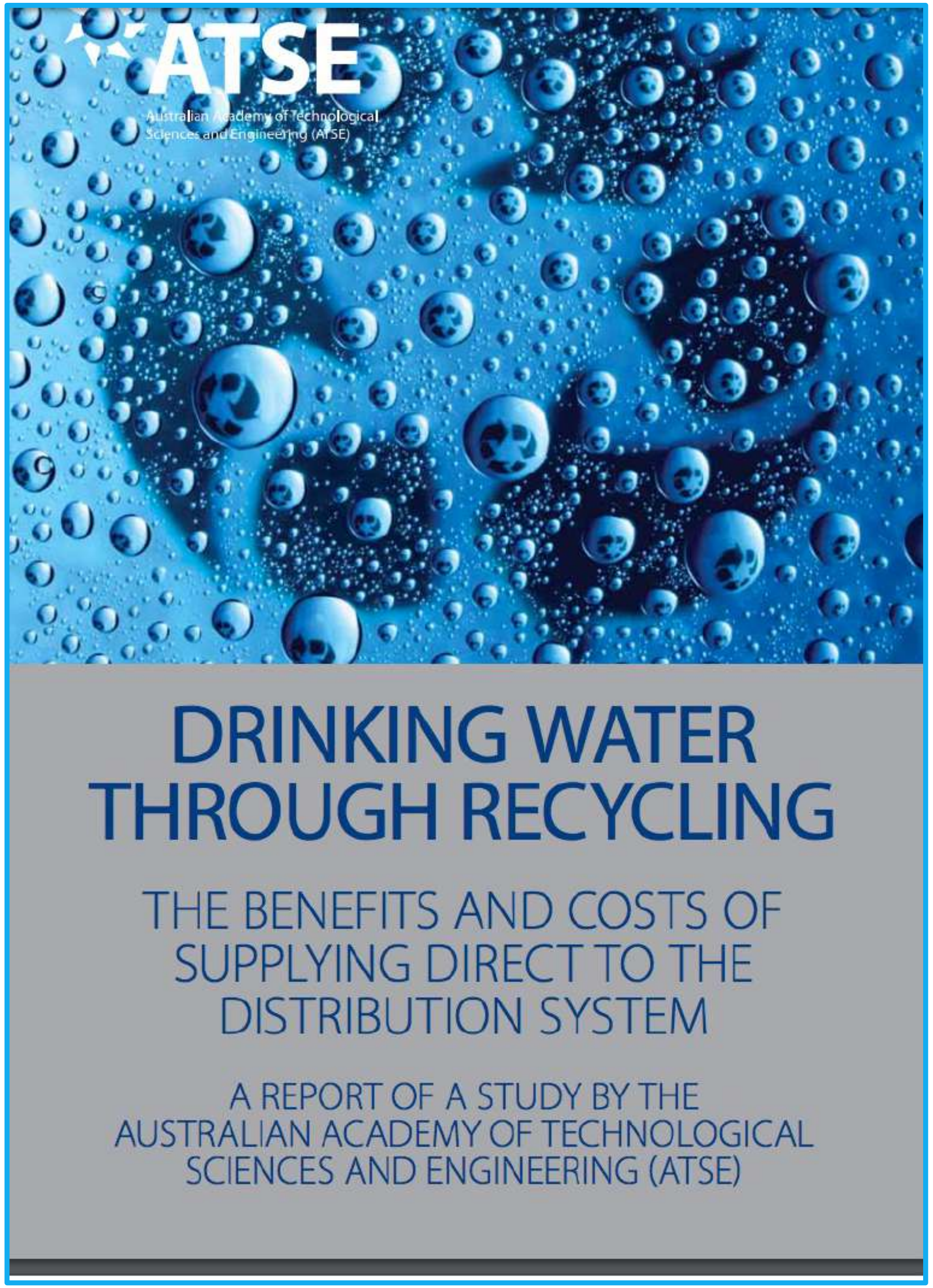


The limitations of using treated wastewater as drinking water source: Introducing the subject of Direct Potable Reuse (DPR) versus Indirect Potable reuse (IPR).



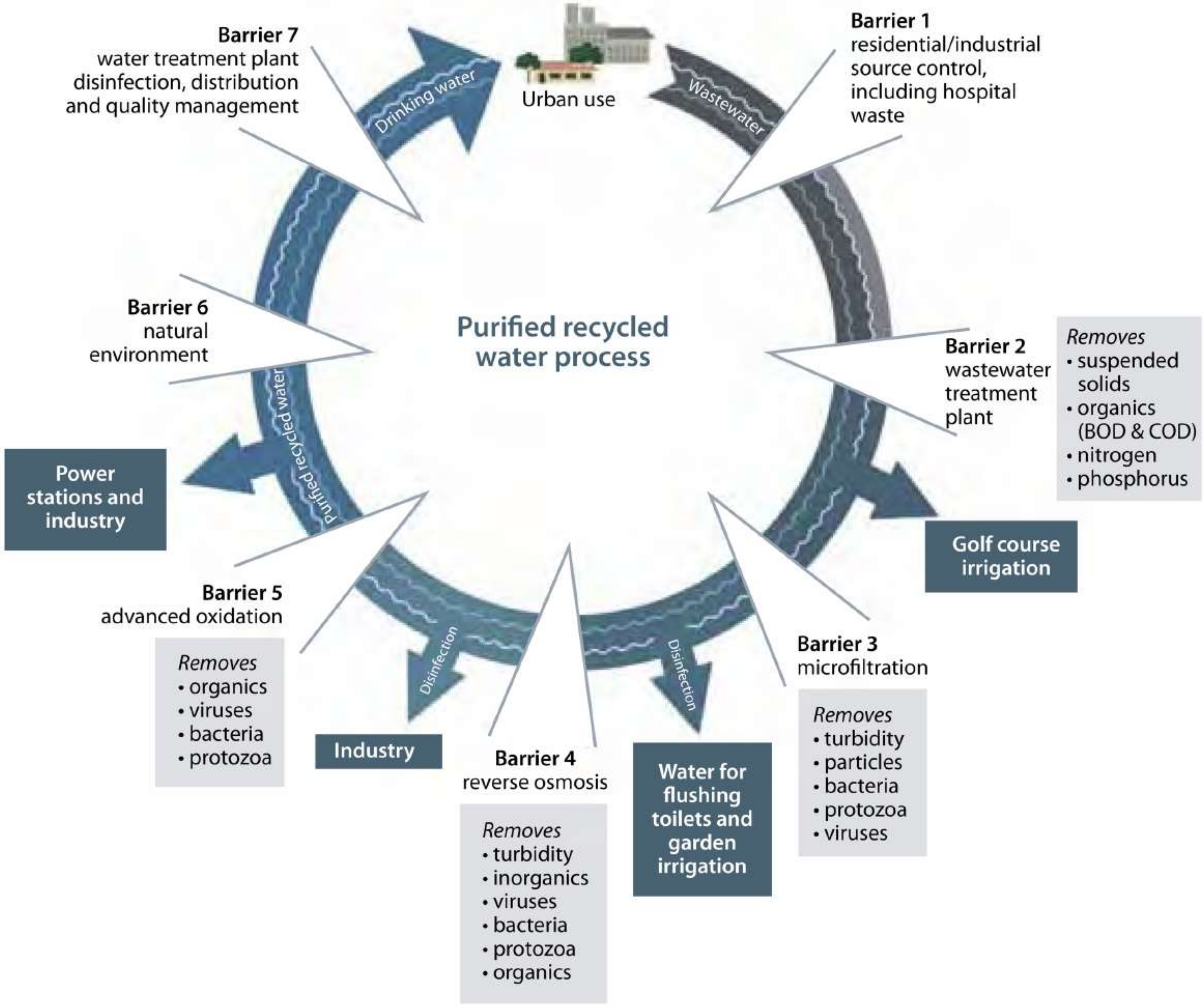
Direct Potable Reuse and Indirect Potable Reuse

The US EPA Guidelines for Water Reuse describe DPR as follows (US EPA 2012):

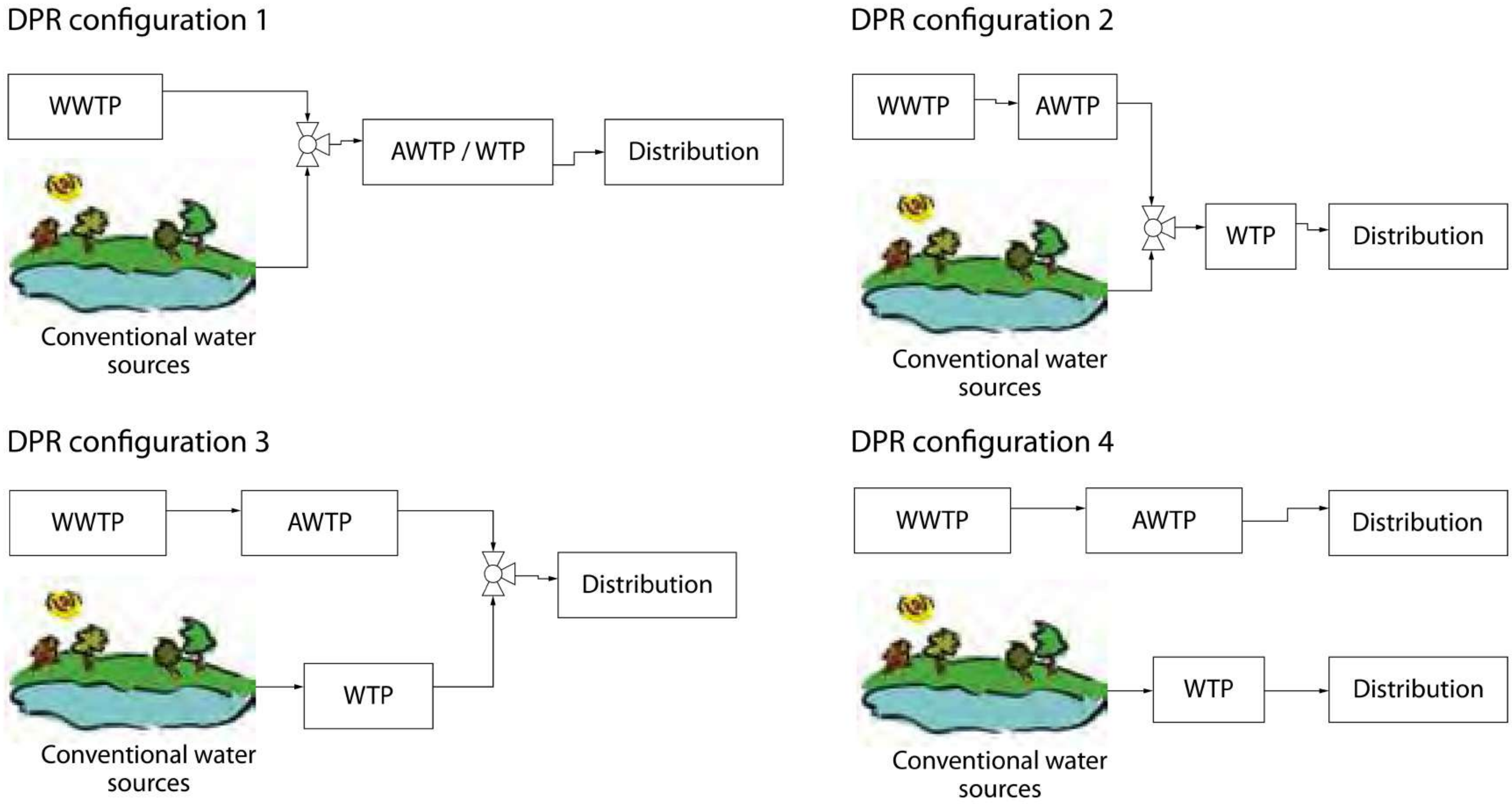
> *DPR refers to the introduction of purified water, derived from municipal wastewater after extensive treatment and monitoring to assure that strict water quality requirements are met at all times, directly into a municipal water supply system. The resultant purified water could be blended with source water for further water treatment or could be used in direct pipe-to-pipe blending, providing a significant advantage of utilizing existing water distribution infrastructure.*

The major difference between DPR and IPR, i.e. the use of environmental buffers, has been attributed a number of important functions. These include: additional treatment of pathogens and chemical contaminants; the provision of 'time to respond' to potential water treatment incidents; and improvement of public perceptions of potable water reuse. In order to maintain appropriate levels of safety, reliability, and public acceptance, such functions would need to be performed in any DPR system by engineered or other processes. This requires sophisticated approaches to water quality monitoring techniques, process reliability assessment, personnel training, engineered water storage design, and community engagement in particular.

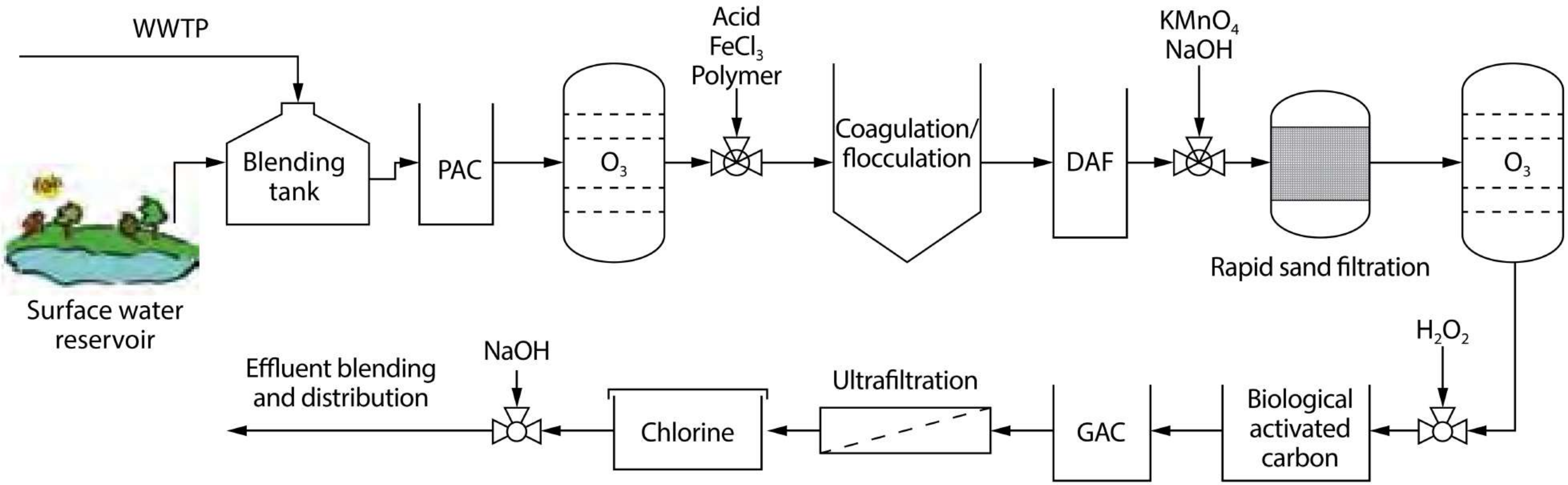
The purified recycled water process including Barrier 6 (natural environment) (QWC 2007).



Direct potable reuse: four configurations of water sources, treatment processes and blending.



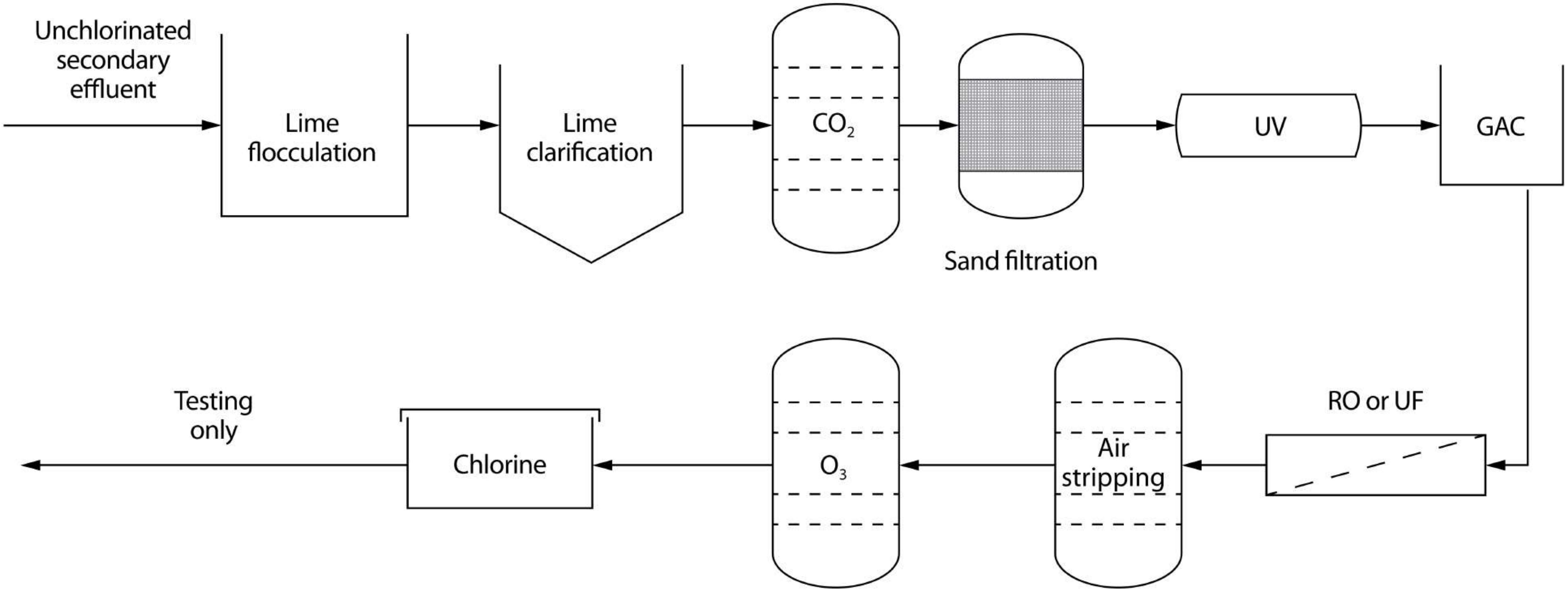
Process flow diagram for the New Goreangab Water Reclamation Plant .



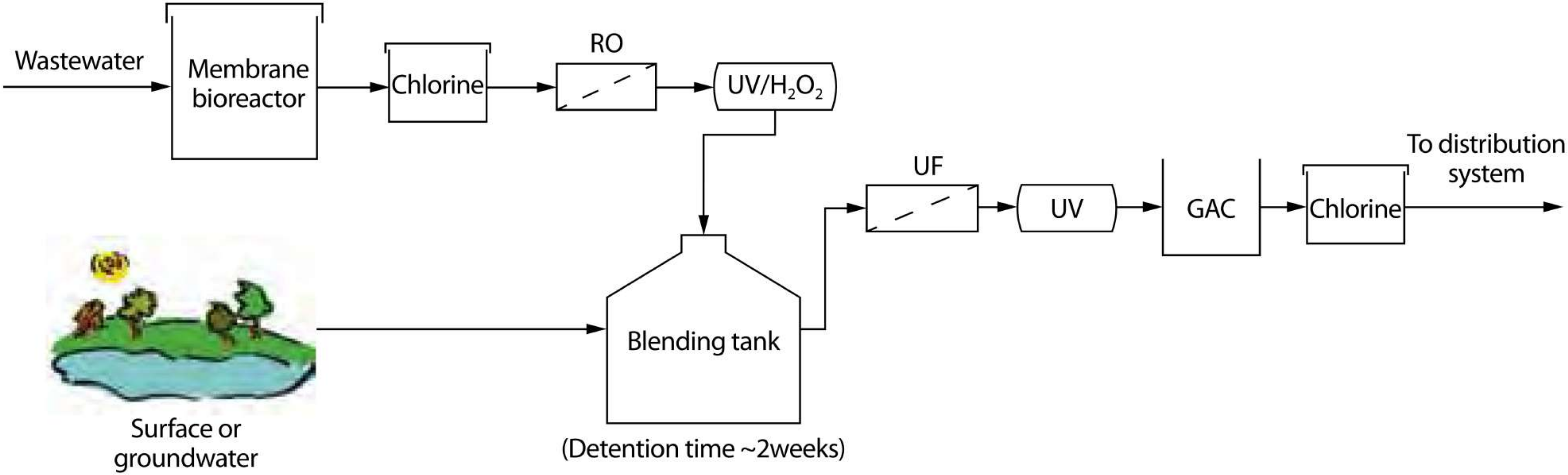
PAC powdered activated carbon

GAC granular activated carbon

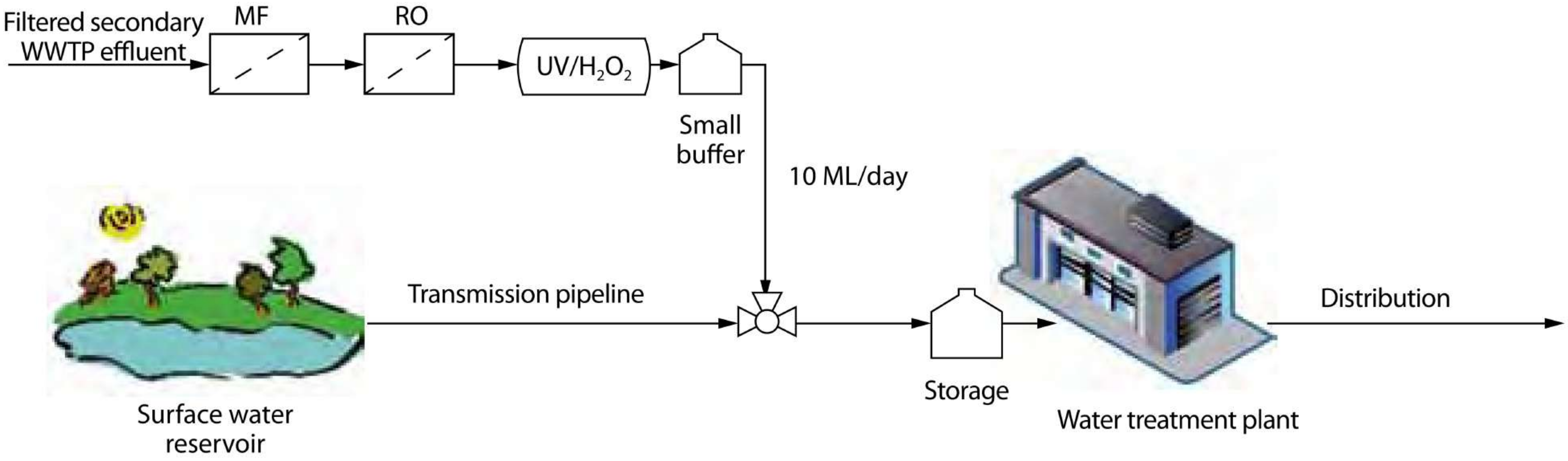
Process ow diagram for the Denver DPR Demonstration Project.



Process flow diagram for Cloudcroft DPR project.

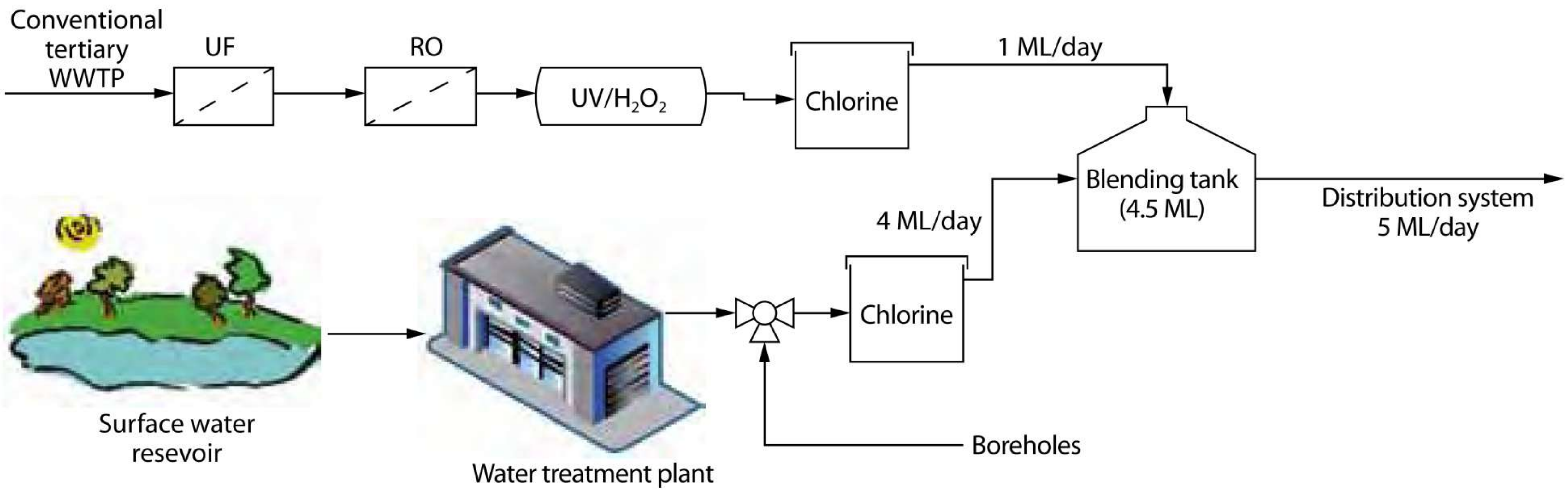


Process flow diagram of the Big Spring DPR scheme.



MF microfilteration

Process flow diagram of the Beaufort West DPR Project.



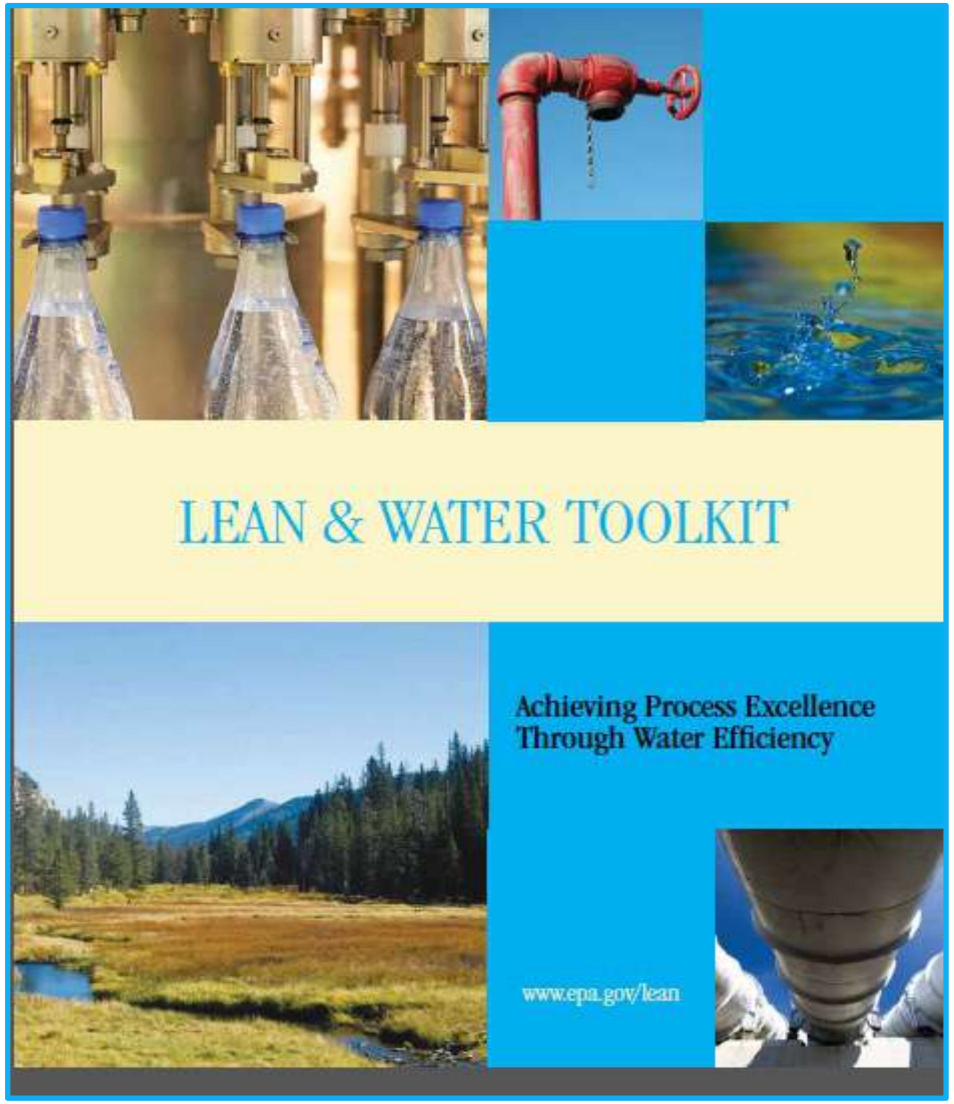
3. Water Conservation in Industry

Water Conservation in Industry

This *Lean and Water Toolkit* describes practical strategies for using Lean manufacturing—the production system developed by Toyota—to reduce water use while improving operational performance. Drawing from the experiences and best practices of multiple industry and government partners, this toolkit explores opportunities to identify and eliminate "water waste," including:

- Water losses and leaks
- Non-value added or inefficient use of water
- Missed opportunities to reuse water
- Wastewater discharges
- Unnecessary water use and risks throughout the supply chain
- Missed opportunities to address customers' water-efficiency goals

This toolkit is a supplement to EPA's *Lean and Environment Toolkit* (www.epa.gov/lean/toolkit), which addresses all types of environmental wastes and improvement opportunities.



United States Environmental Protection Agency
www.epa.gov/lean
October 2011
EPA-100-K-11-003

Industrial Water Metrics

Facility-Wide Metrics

- ✓ Volume of water used each month or other appropriate time period (e.g., gallons/month or gallons/shift)
- ✓ Volume of wastewater (e.g., gallons/month or gallons/shift)
- ✓ Water used for specific end uses (e.g., gallons/per month for outdoor irrigation, cooling water evaporation, heated process water, bathrooms and kitchens, etc.)*

Metrics Normalized to Production

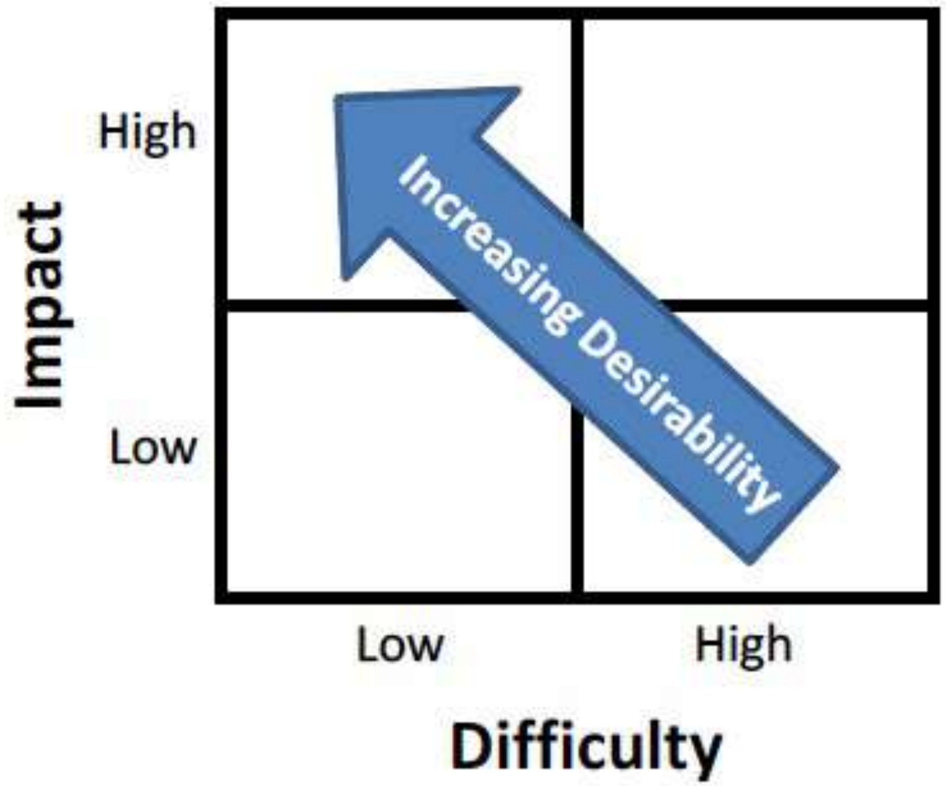
- ✓ Volume of water used per product (e.g., gallons/pound of product, gallons/product)
- ✓ Volume of wastewater discharged per product (e.g., gallons/pound of product or gallons/product)

Lean and Water Implementation Strategies

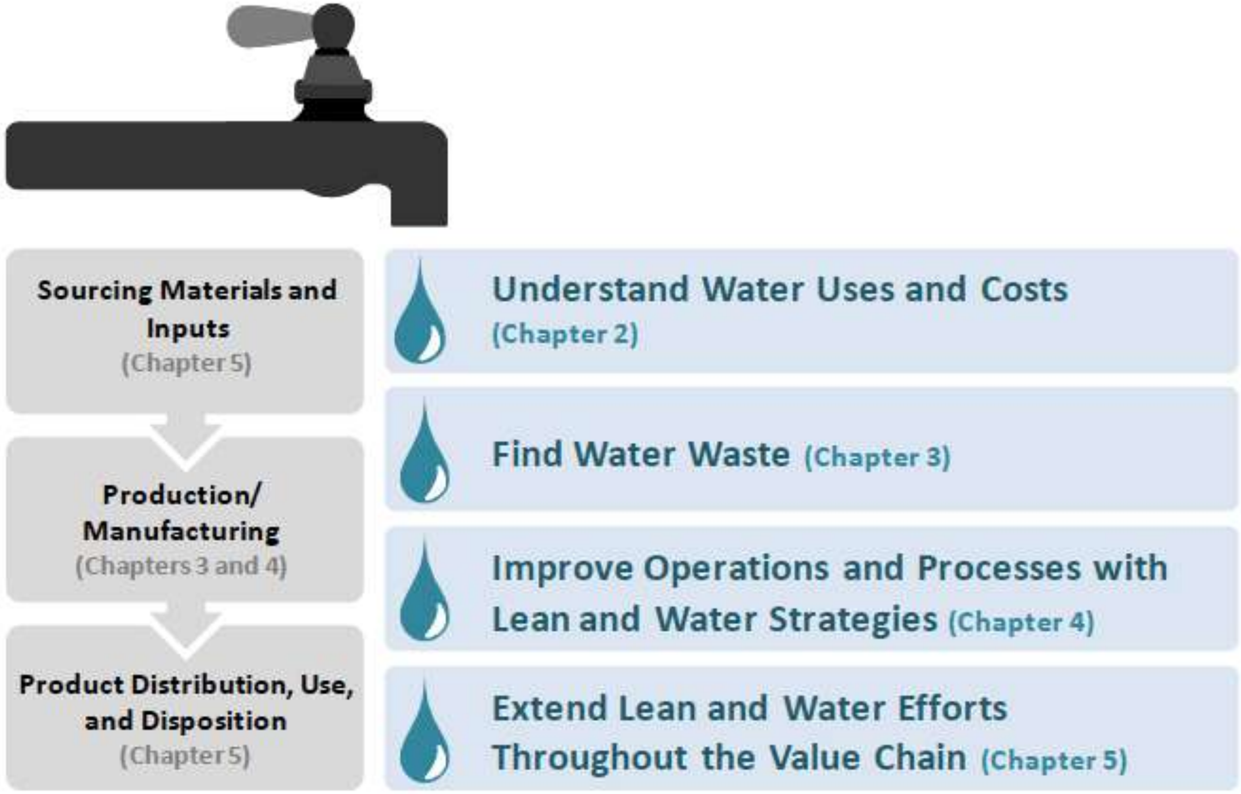
Connect Lean and Water Efforts to Sustainable Water Management Strategies

Lean and Six Sigma provide operational tools that can support a broader corporate water sustainability strategy. Lean's focus on performance measurement, continual improvement through employee engagement, waste elimination, improved efficiency, increased profits and customer satisfaction can be leveraged to support corporate water management efforts to measure and report water use, factor water into business decisions, and implement the practical and effective solutions. If your organization already has a sustainability policy and/or specific water efficiency goals, consider how Lean and water strategies could be used to enhance and accelerate those efforts.

Figure 1: Impact-Difficulty Matrix



Definition of Water Wastage in Industry



To Consider

- ✓ Is water use responsible for major costs, waste, or risk at your organization? If you don't know, how would you find out?
- ✓ How has Lean affected your organization's use of water?
- ✓ How could your organization benefit from efforts to reduce water waste using Lean? (Think about time and cost savings, reduced risks and liabilities, added value to customers, etc.)
- ✓ What ideas do you have for reducing water waste using Lean?

Water-Intensive Industries

Water Consumption in Selected Industries

- ✓ Agriculture
- ✓ Apparel
- ✓ Beverages
- ✓ Biotechnology/pharmaceuticals
- ✓ Electric power
- ✓ Forest products
- ✓ High-tech (including semiconductor manufacturing)
- ✓ Metals/mining

Table 1: Typical Water Use Per Ton of Product

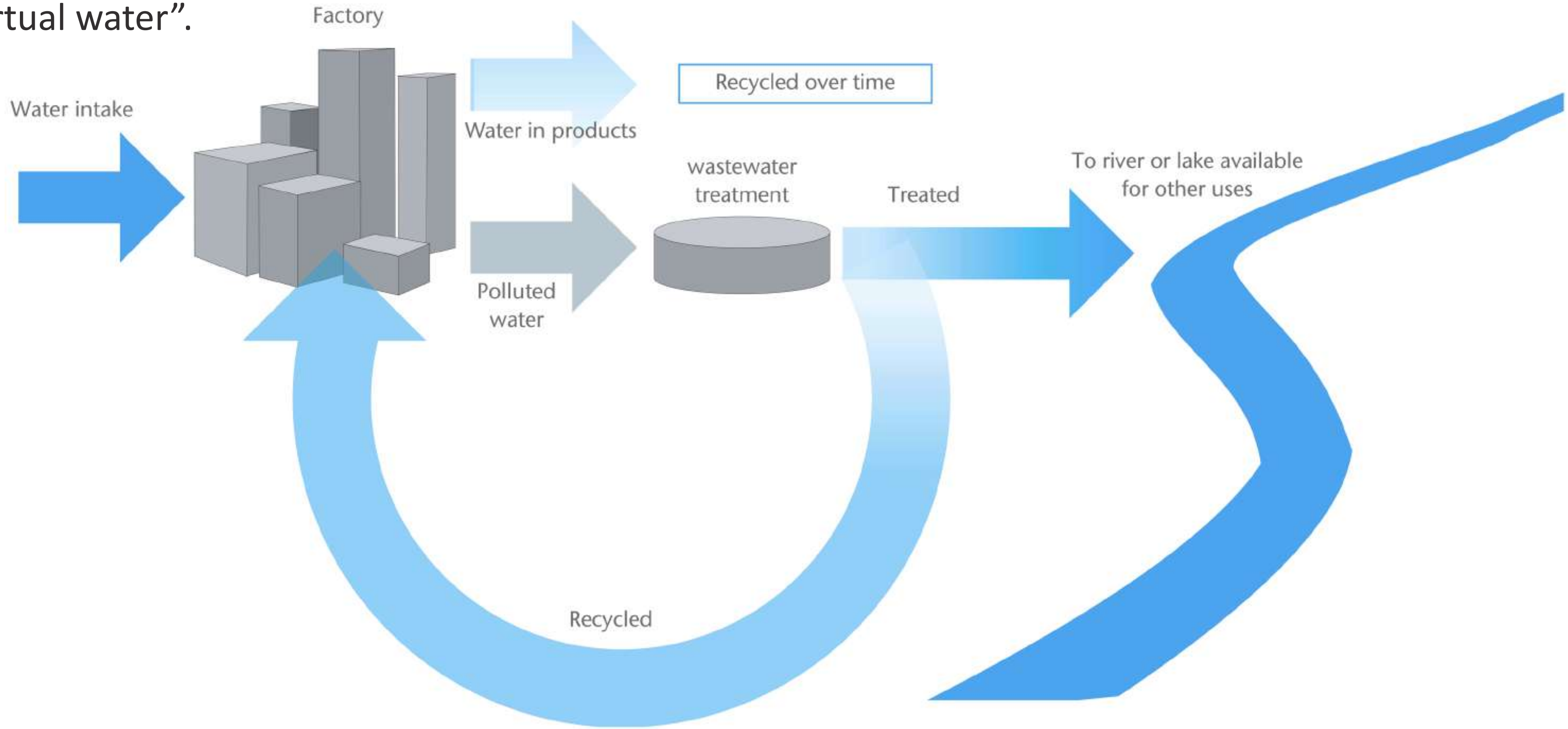
Paper	21,000–528,000 gallons
Beer	2,113–6,604 gallons
Sugar	792–105,668 gallons
Steel	528–92,460 gallons
Soap	264–9,246 gallons
Gasoline	26–10,566 gallons

Source: United Nations World Water Assessment Programme, United Nations World Water Development Report: Water in a Changing World, 2009, available at: www.unesco.org/water/wwap/wwdr/wwdr3/.

Water for products

Many businesses, notably the food, beverage and pharmaceutical sectors consume water by using it as an ingredient in finished products for human consumption. Think of dairy products, soups, beverages and medicines that are delivered in liquid form.

Some water experts are using the term “virtual water” to describe the water that is embedded both in agricultural and manufactured products, as well as the water used in the growing or manufacturing process. When a country exports goods, it is exporting “virtual water”.



Source: Reference 1

Water End Uses: How water is used at industrial facilities

In order to reduce water waste in industry, it is important to understand the many ways that water is used within facilities. *Understanding water end uses is critical to identifying water savings opportunities.* While end uses of water vary by industry and by facility, there are categories of water use that are present at most industrial facilities. Water use in most industries can be classified into the following broad end uses:

- Production processing and in-product use
- Auxiliary processes (e.g., pollution control, labs, and cleaning)
- Cooling and heating (e.g., cooling towers and boilers)
- Indoor domestic use (e.g., restrooms, kitchens, and laundry)
- Landscape irrigation

Common Costs Associated

Raw Material Costs:

- ✓ Water purchased from utilities; marginal costs of purchasing additional water versus costs of conservation
- ✓ Cost of water treatment, filtering, and softening before use
- ✓ Costs for chemicals needed to treat and manage water

Energy Costs:

- ✓ Cost of energy to heat water
- ✓ Cost of energy to pump water from its source, or within the facility itself
- ✓ Energy and labor costs for operating and maintaining water-using equipment

Pollution Control Costs:

- ✓ Wastewater and stormwater service rates, including surcharges
- ✓ Total cost of treating wastewater for disposal, including labor, energy, chemicals, equipment, and residual disposal
- ✓ Marginal costs of increasing effluent treatment capacity when water demand increases

Regulatory Compliance Costs:

- ✓ Labor costs for regulatory compliance activities such as completing permit applications, monitoring compliance, and reporting wastewater discharges to regulatory agencies

Source: Adapted from North Carolina Department of Environment and Natural Resources, Water Efficiency Manual for Commercial, Industrial and Institutional Facilities, May 2009, available at www.p2pays.org/ref/01/00692.pdf.

Water use in a typical industrial facility:

This is the basis for designing a water audit form to investigate magnitude of losses and potential savings

Process and Equipment Use	Other Facility Support
• Cleaning, Washing, Rinsing • Metal Finishing • Painting • Dyeing and Finishing • Photo Processing • Process Water Reuse • Product Fluming (Water Transport) • Pretreatment/filtration systems • Pump and Conveyor Lubrication • Water Use in Products **Cooling and Heating** • Single-Pass Cooling • Cooling Towers • Boilers, Hot Water, Steam Systems • Air Washers • Boiler Scrubbers	• Floor Washing • Air Emission Wet Scrubbers • Building Washing • QA/QC Testing • Laboratories • Landscaping and Irrigation • Dust and Particulate Emission Control • Decorative Fountains and Ponds • Vehicle Washing • Cooling Water for Air Compressors and Vacuum Pumps • Hazardous Waste Storage and Effluent
Sanitary and Domestic • Toilets • Faucets • Urinals • Showers • Wash-up Basins	**Kitchens** • Food Preparation and Cleaning • Dishwashers • Ice Machines • Faucets • Food Disposals

Source: Adapted from North Carolina Department of Environment and Natural Resources, Water Efficiency Manual for Commercial, Industrial and Institutional Facilities, May 2009, available at www.p2pays.org/ref/01/00692.pdf.

Five Water-saving Strategies

- ✓ Adjust water flow
- ✓ Modify existing equipment or install water-saving devices
- ✓ Change to more water-efficient equipment
- ✓ Reuse or recycle water (treat if needed)
- ✓ Shift to a low-water or waterless process

Example of best-practices that need to be introduced to save water in industrial facilities in the cleaning processes

Dry Clean-up First:

✓ Use brooms, brushes, squeegees, and/or other tools to remove materials and debris in dry form before using water for secondary cleaning. (This saves water, reduces wastewater, and enables recovery of process materials.)

Eliminate Unnecessary Water Use for Floor Washing:

✓ Sweep or use a water broom instead of hosing floors.

✓ Spot mop if necessary.

"Mistake-Proof" Your Equipment:

✓ Use hoses that have automatic shut-off nozzles.

✓ Use efficient spray nozzles, high-pressure washers, and/or flow restrictors to clean efficiently while reducing water use. (High-pressure, low-volume sprays generally work better than low-pressure, high-volume sprays.)

Use Efficient Spray Washing and Rinsing Techniques:

✓ Use water wisely, and turn off water when not in use.

✓ Do not use a hose as a broom; doing so wastes time, water, and energy.

✓ Optimize spray and rinsing techniques, and document the best practices in the standard work for the process.

For more suggestions, see North Carolina Department of Environment and Natural Resources, "Water Efficiency Manual for Commercial, Industrial and Institutional Facilities," May 2009, www.p2pays.org/ref/01/00692.pdf.

Good examples of industry success to apply the best practices for water conservation

A textile firm in India reduced its water consumption by over 80%, by replacing zinc with aluminum in its synthetic fiber production, by reducing trace metals in wastewater thereby enabling reuse and by using treated water for irrigation by local farmers.

A plant converting sugar cane into sugar in Mexico reduced its consumption of water by over 90% by improving housekeeping and segregating sewage from process wastewater.

What can industry do to alleviate water stress?

Put its own house in order by

Measuring and monitoring water use

Understanding the water “footprint” of the business both inside and outside the corporate “fenceline”.

Continuing to reduce water consumption

per dollar of output and work towards the goal of zero discharge by:

- Recycling and reusing water
- Lowering toxic and other contaminants in all operations involving water
- Changing production processes to be more water efficient

Encouraging suppliers and purchasers

up and down the supply chain to adopt best management practices – assisting small and medium sized enterprises to improve water management.

Innovating

Searching for new more efficient water treatment technologies.

Enter into creative partnerships with

Municipalities

where business operates to develop cost-effective water supply and sanitation options.

Non-governmental groups

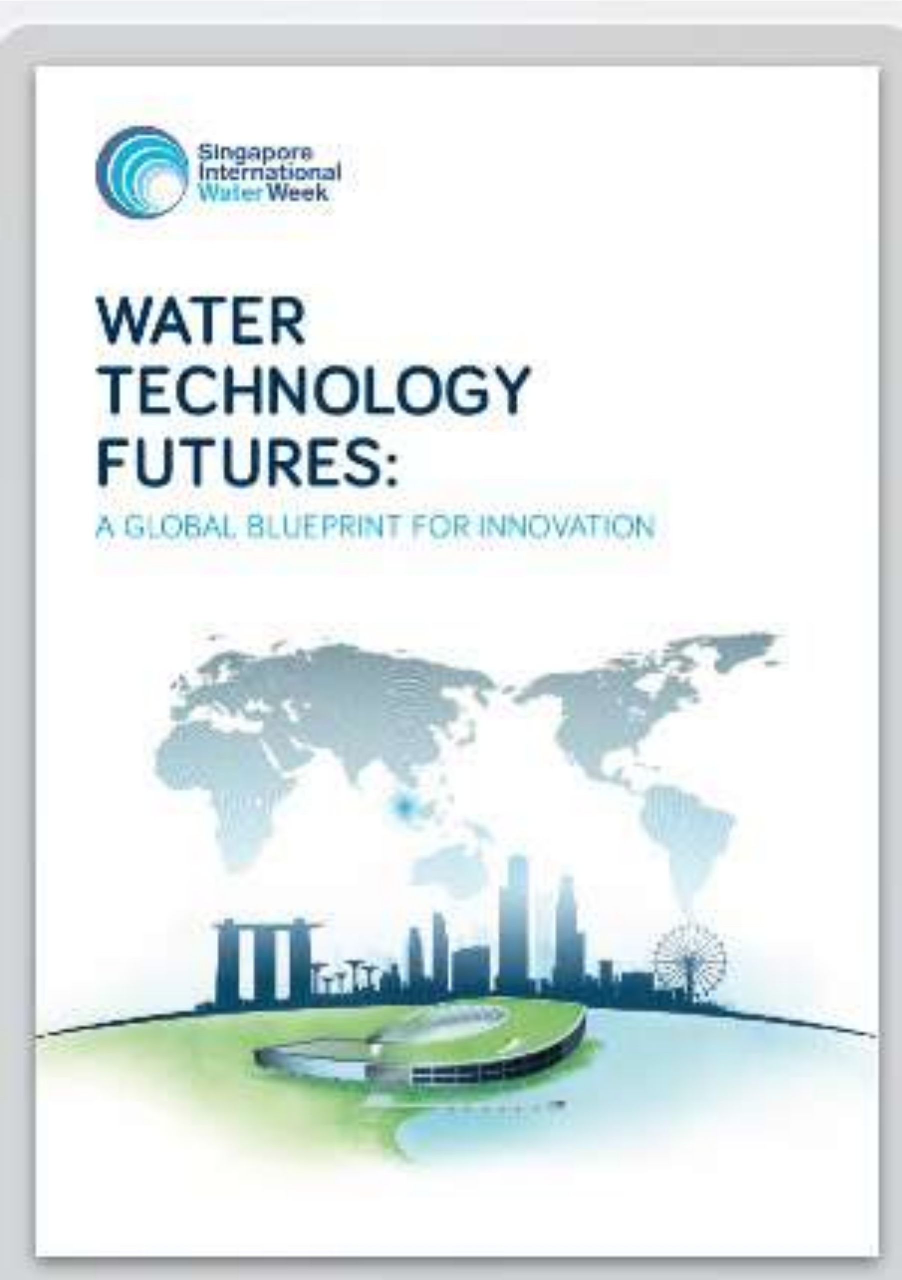
to encourage water conservation and improved water management systems.

The scientific community

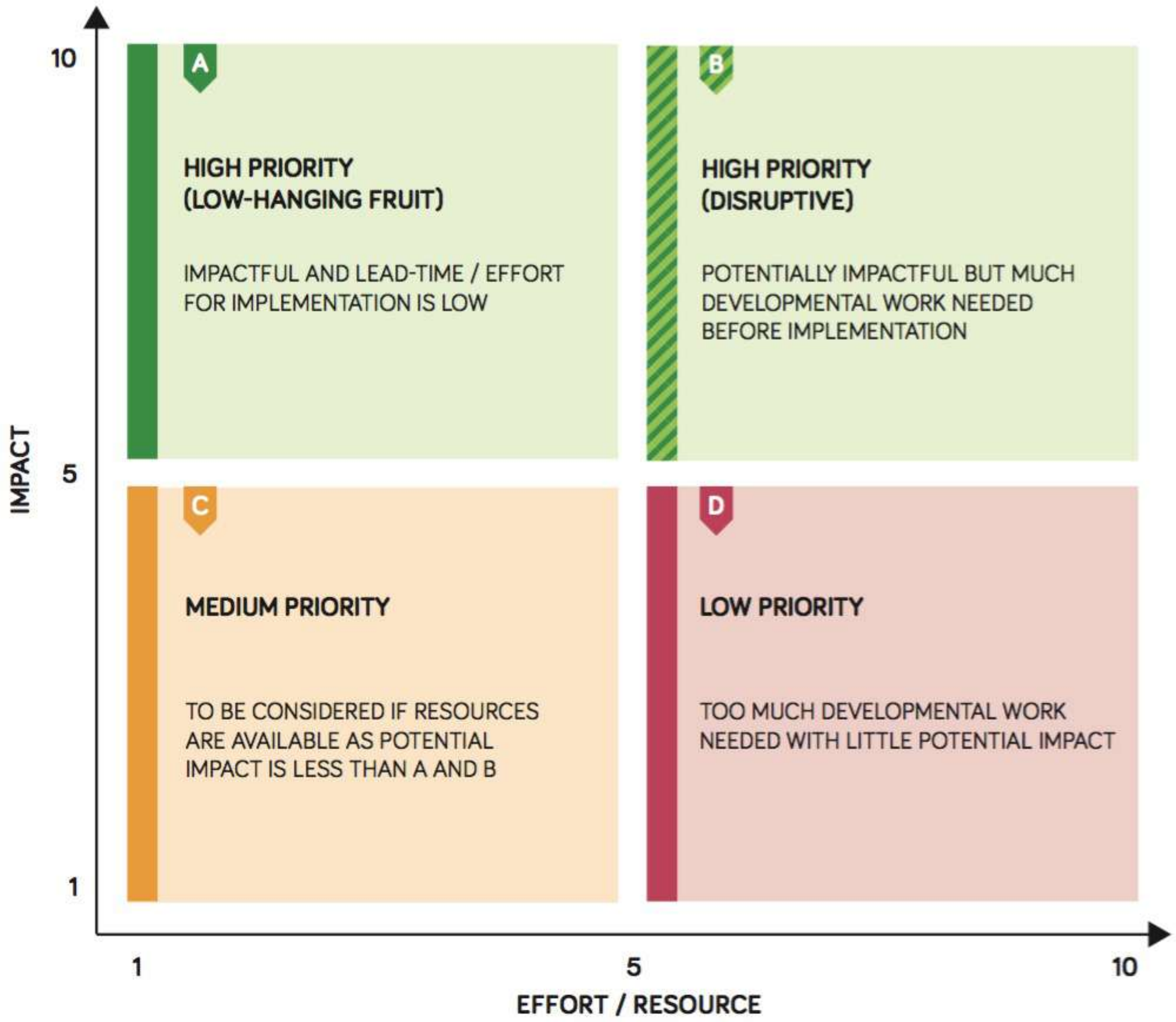
to improve understanding of water resources and their management and to develop technologies to get the most value out of the water cycle.

Source: Reference 1

4. Future of Water Technology


Singapore International Water Week
WATER TECHNOLOGY FUTURES:
A GLOBAL BLUEPRINT FOR INNOVATION

CLASSIFICATION OF TECHNOLOGY FOCUS AREAS



GLOBAL TECHNOLOGY ROADMAP

8 KEY DRIVERS FOR INNOVATION:

1. PROTECTION OF WATER QUALITY
2. CLIMATE CHANGE / EXTREME WEATHER EVENTS
3. DEMAND MANAGEMENT
4. NEED FOR NON-CONVENTIONAL WATER SOURCES
5. WATER-FOOD-ENERGY NEXUS
6. ENVIRONMENTAL SUSTAINABILITY, E.G. WASTE MINIMISATION / RESOURCE RECOVERY
7. FIT FOR LOCAL CONTEXT
8. GOVERNANCE / LEADERSHIP

	JOINT TECHNOLOGY FOCUS AREAS	CLEAN WATER TECHNOLOGY FOCUS AREAS	WASTEWATER TECHNOLOGY FOCUS AREAS
A HIGH PRIORITY (LOW-HANGING FRUIT)	• Industrial Water Technologies • Separation / Membrane Technologies (Wastewater) • Biological Processes (Wastewater)	• Low-Energy Seawater Desalination • Water Demand Management • Network Asset Management • Storm Water Management for Flood Control and Water Supply	• Optimisation of Wastewater Collection Systems • Improving Energy Efficiency and Generating Energy from Wastewater Treatment • Sludge Management
B HIGH PRIORITY (DISRUPTIVE)	• Low Energy and High Water Recovery for Reuse • Decentralised Treatment Technologies • Biological Processes (Clean Water)	• Low-Temperature / Energy-Efficient Thermal Desalination • Brine Management	• Source Separation for Wastewater Management • Point of Use Reuse
C MEDIUM PRIORITY	• Separation / Membrane Technologies (Clean Water) • Advanced Oxidation Processes • Water Quality Analytics • Man-less Systems / Automation		• Nutrient Recovery • Fit-for-Purpose Reuse • Disinfection • Low-Tech Solutions • Natural Systems
D LOW PRIORITY			• Electrochemical Processes • Smaller-Footprint Treatment Technologies

CLEAN WATER TECHNOLOGY FOCUS AREAS

A

HIGH PRIORITY (LOW-HANGING FRUIT)

- Low-Energy Seawater Desalination
- Water Demand Management
- Network Asset Management
- Storm Water Management for Flood Control and Water Supply

B

HIGH PRIORITY (DISRUPTIVE)

- Low-Temperature / Energy-Efficient Thermal Desalination
- Brine Management

CASE STUDY 8

HIGH STRENGTH AND POWER DENSITY MEMBRANES FOR MAXIMISING ENERGY GENERATION FROM THE PRO PROCESS

National University of Singapore

Reverse osmosis (RO) is the premier seawater desalination process used across the globe, gaining strong market share over thermal methods over the years because of lower energy use. However, energy consumption in seawater reverse osmosis (SWRO) can still be a pain point – it can comprise over 50% of a desalination plant's total operational costs. Alternatives are being widely sought among the industry. Concerns over high energy prices and a drive towards using renewable energy sources has brought pressure retarded osmosis (PRO) into the picture.

CASE STUDY 10

REAL-TIME ANALYTICS FOR BETTER NETWORK ASSET MANAGEMENT

Visenti Pte Ltd

The future city may not yet be a place for swerving hoverboards or flying vehicles but it is likely to be kitted out with thousands of sensors monitoring the moment-to-moment functioning of city infrastructure. When it comes to water supply in such "smart" cities, utilities now have the capability to deploy sensors onto their vast pipe networks. These sensors detect pressure changes within the network and are able to provide valuable data on asset wear and tear.

SWITCH

Sustainable Water Management *in the City of the Future*

Editors
C.A. Howe, K. Vairavamoorthy and N. P. van der Steen

Authors
C.A. Howe, J. Butterworth, I.K. Smout, A.M. Duffy and K. Vairavamoorthy

Findings from the SWITCH Project
2006-2011

Research focused on the areas of demand management, soil aquifer treatment and capture/use of rainwater. There were a number of projects in this context, including the following:

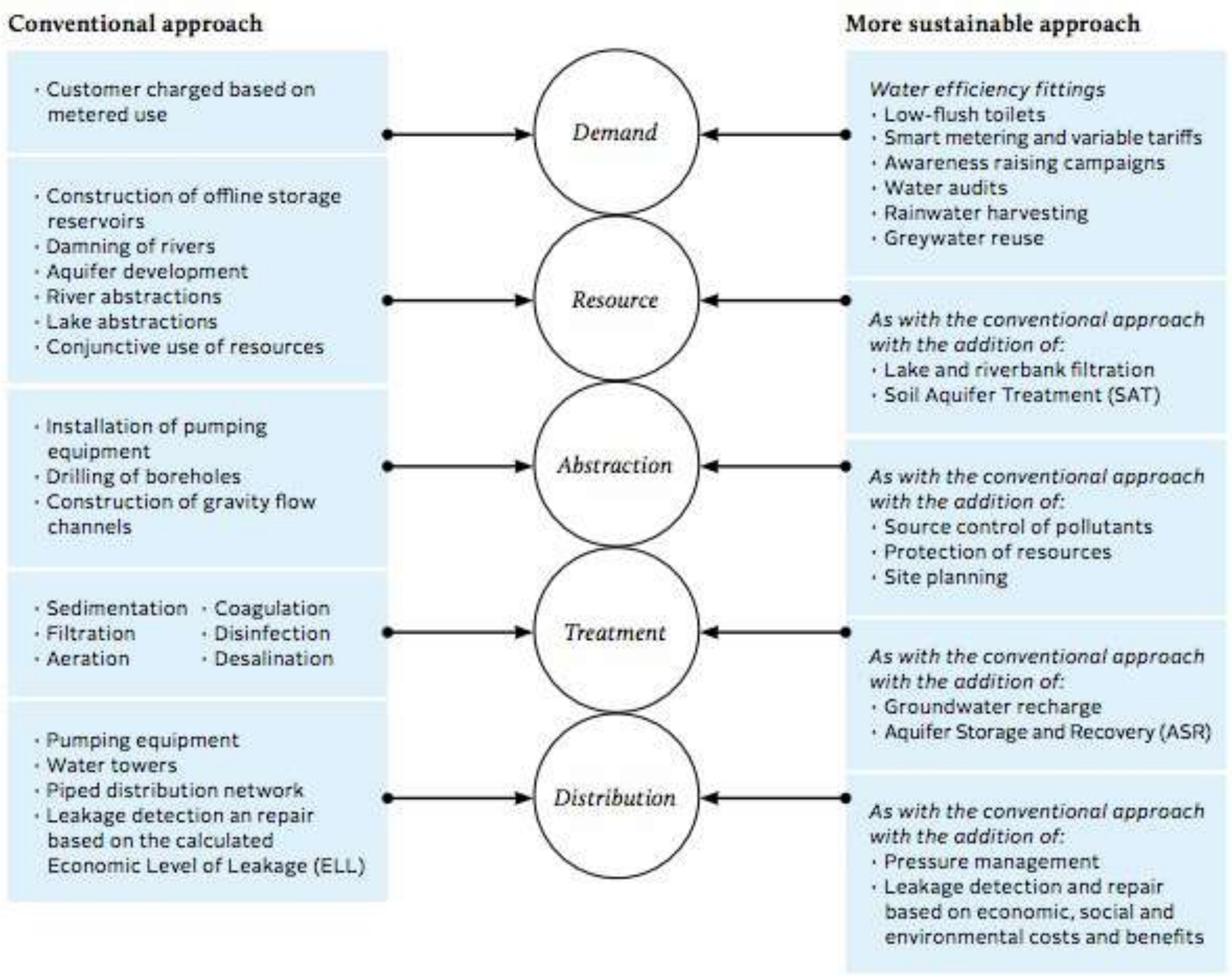
Managing Water Demand considered how cities in industrialized and developing countries could use water demand management to meet the challenge of increasing demands. Research considered end-use and options analysis and various strategies and tools at both customer and utility level to maximize the benefits of water services while minimizing water usage and water losses.

Water Security through Re-use reviewed the effectiveness of Soil Aquifer Treatment (SAT) and Engineered Environmental Buffer technologies to enable safe water reuse so that wastewaters treated could be used multiple times through return to the supply side of the infrastructure. Analysis was done of the removal of contaminants by different combinations of SAT, membrane systems and conventional pre-treatment and post-treatment systems.

Water Quality improvement was explored by modelling viral lifespans and transport in aquifers. The removal of pharmaceutically active compounds and endocrine-disrupting compounds was researched for bank filtrationm and artificial recharge.

Sustainable water management as viewed in the study. It is composed of five components: Demand, Resource, Abstraction, Treatment and Distribution.

The shown diagram compares the conventional approach and the more sustainable approach.



Demand Management

Alexandia Case study: The shown table presents the measures identified to improve the situation in city water demand management

Code		Water saved or supplied in 2037 (mm^3/year)	Unit cost (PV$/PV$m^3$)
DM1	Household water saving fittings retrofit	26	0.08
DM2	Toilet replacement program for households	6	0.53
DM3	Tourist & commercial buildings audit & retrofit	30	0.11
DM4	Government buildings audit & retrofit	41	0.08
DM5	Industrial facilities audit & retrofit	34	0.06
DM6	System leakage reduction	59	0.02
DM7	Tariff reform	57	0.00
DM8	Agricultural efficiency offsets (to increase supply to the city)	75	0.01
DM9	Appliance efficiency regulation (at the national level)	21	0.02
S1	Desalination for coastal resorts	42	1.15
S2	Wastewater reuse for industrial properties	32	0.60
S3	Agricultural drainage water desalination & reuse for industries & coastal resorts (non-potable use)	62	0.63
S4	Wastewater reuse for agriculture	63	0.48
S5	Groundwater for urban green space irrigation	18	0.48
S6	Local wastewater reuse for new developments (incorporating decentralised sewer systems)	37	0.40
S7	Local wastewater reuse & nutrient recovery (incorporating decentralised sewer systems & urine diversion)	37	0.58

Issues that are commonly associated with urban water supply systems.

- Unsustainable use of local resources: The need to meet increasing demands can cause over-abstraction from local resources. This leads to depleted groundwater levels and low river flows which have consequences for future supplies and downstream users, as well as causing damage to aquatic ecosystems
- Energy use: Water supply is reliant on energy for treatment and pumping, as well as when supplies are imported from elsewhere. This leaves the service vulnerable to power cuts and variations in fuel costs, and typically increases a city's carbon emissions.
- Pollution: Upstream water pollution increases treatment costs and can cause reduced use and abandonment of water supply sources.
- Non revenue water: In some cities as much as half of the treated water entered into the distribution network is lost through leakages and illegal connections.
- Waste of resources: Water treated to potable standard is used for non-potable purposes such as toilet flushing, garden use and industry. This, along with leakage from the distribution network, results in expenditure in unnecessary treatment.
- Cost: The cost of constructing, operating and maintaining water supply pumping, treatment and distribution infrastructure is high and can not always be reclaimed from the customer.
- Non-flexible: Water treatment plants and distribution infrastructure have a design capacity based on forecasted water demands. These systems are not easily adapted if the forecasts prove to be too high or too low.
- Inefficient use: Where water is heavily subsidised or charged based on a fixed rate, users have little financial incentive to use it sparingly. This leads to wasteful usage and high consumption rates.

Tools to Assess Water Supply Risk and Vulnerability

- **Global Water Tool (World Business Council for Sustainable Development)**—Designed for companies and organizations to map their water use and then assess risks relative to their global operations and supply chains.
- **Aqua Gauge (Ceres)**—A way for companies to assess, improve and communicate their corporate-wide water risk management approach.
- **Watersketch Toolbox (Finnish Environment Institute)**—Offers information and practical tools and methods for sustainable river basin planning and management.
- **Local Water Tool (GEMI)**—Intended for companies and organizations to evaluate the external impacts, business risks, opportunities and management plans related to water use and discharge at a specific site or operation.
- **CREAT, Climate Resilience Evaluation and Awareness Tool (EPA)**—Organizes available climate data and guides users through a process of identifying threats, vulnerable assets and adaptation options to reduce risk.
- **Aqueduct Water Risk Atlas (World Resources Institute)**—Intended for companies, investors, governments and communities to better understand where and how water risks are emerging around the world.
- **Sea Level Rise Tool For Sandy Recovery (NOAA)**—

Provides a set of map services to help communities, residents, and other stakeholders consider risks from future sea level rise in planning for reconstruction following Hurricane Sandy.

Reference 2

References

1. World Business Council for Sustainable Development, Facts and Trends on Water, March 2006

2. EPA, Promoting Technology Innovation for Clean and safe Water, Water Technology Innovation Blueprint, version 2, April 2014