Regional Training and Study Tour on optimal irrigation management (12-16 June 2013– CIHEAM Bari, Italy)

Training module 3:
Safe reuse of non-conventional water resources in agriculture

Alessandro Gaetano Vivaldi

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TEACHING

In the past years, I have gained experience in teaching courses on sustainable orchard management systems and applied statistics for biological sciences at undergraduate and graduate levels across different programs (Master Program on “Sustainable management of the Mediterranean countryside” 6 ECTs credits, “Management and conservation of the Agri-Forest environment.” 3 ECTs credits, Ph.D. School of “Biodiversity, Agriculture and the Environment” 2 ECTs credits, etc.) **at the University of Bari**.

- **“Sustainable fruit tree cropping systems and precision agriculture”**, the main expected learning outcomes for the students are related to integrated fruit production; **reuse of reclaimed waters and resulting effects to soil and plants;** understanding the relationships between plants and the environment, physiologic and soil parameters and datasets; the use of decision making methods and tools for evaluating the effects of different agronomic management techniques; methods and tools for monitoring crop and soil parameters;**.**

- **“Applied statistics for biological sciences”**, the main expected learning outcomes for the students are related to basic foundations in statistical methods and tools, and data analysis using the statistical software R.

RESEARCH

My research interests focus primarily on the reuse of reclaimed water in agriculture and on investigating solutions and practices for sustainable orchard systems management. Both these subjects are multifaceted and can be divided into different research topics. In particular, the first subject can be divided into three main study topics:

a) assessing the dynamics of nutrients application and uptake in soil-water-plant systems;

b) evaluating the environmental and microbial impacts of reclaimed water on orchard systems;

c) developing viable solutions (methodologies, tools and practices) for achieving ecologically sustainable reuse of reclaimed waters.

d) Use of remote sensing to monitor crops irrigated with reclaimed water

General introduction to Module 3

1) **Transitioning to a Water-Smart Society**
(40 minutes)

2) a. **Reclaimed water treatment, standards, and reuse: Apulia Region context**
2) b. **A user-friendly tool for a sustainable reuse of reclaimed water in agriculture**
(2 hours)

3) **Explore international guidelines to compare and interpret the difference between water quality standards for reuse in agriculture**
(1 hour)

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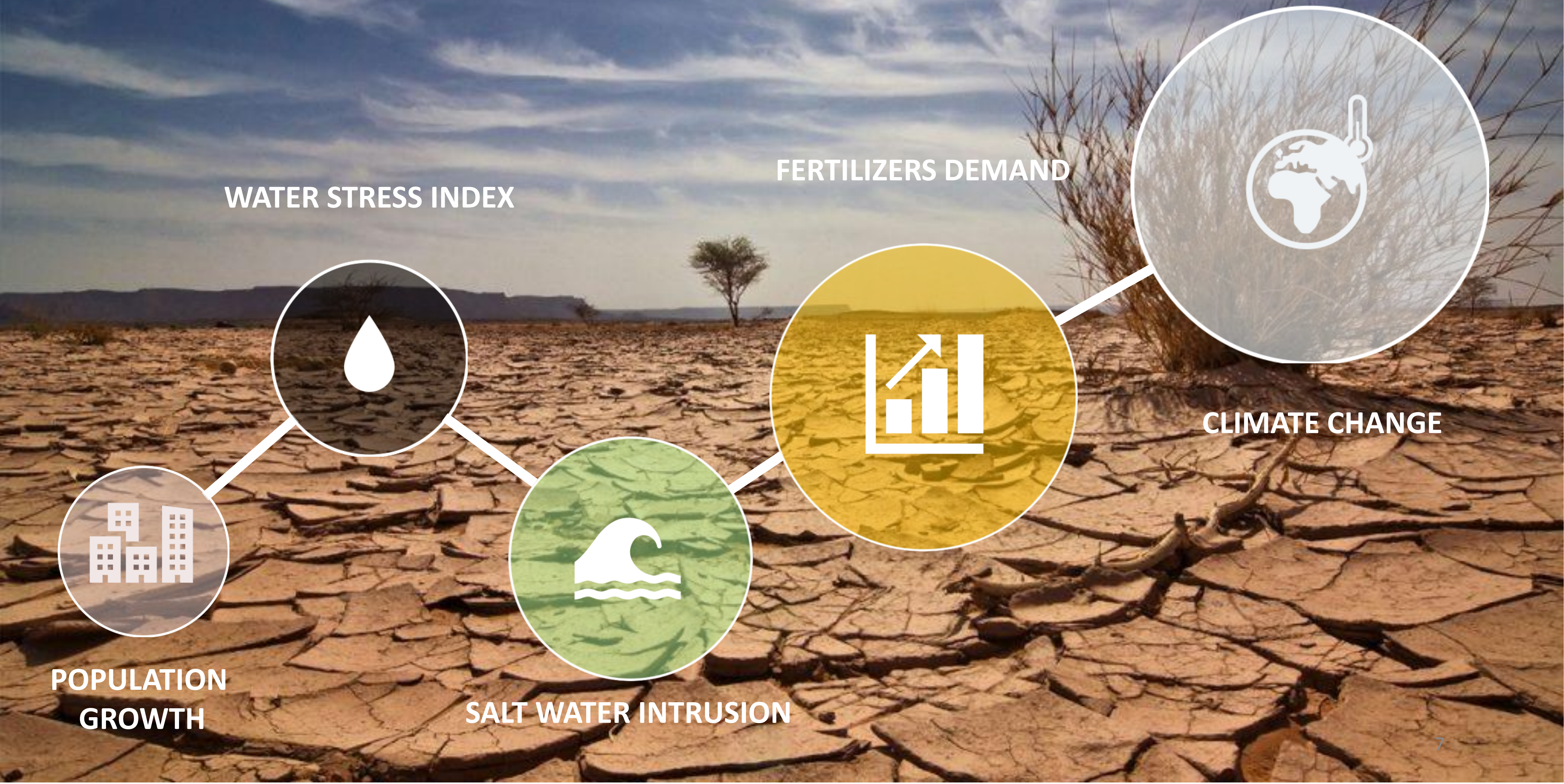
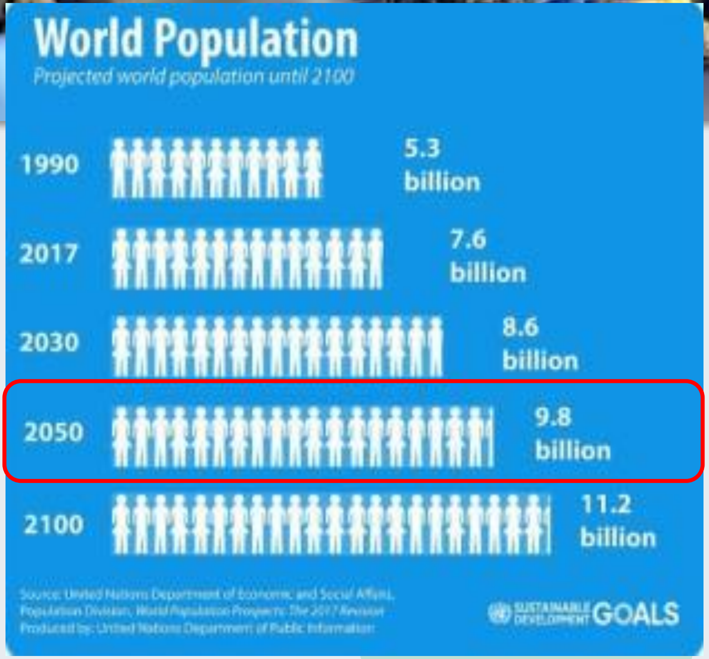
INTRODUCTION



INTRODUCTION

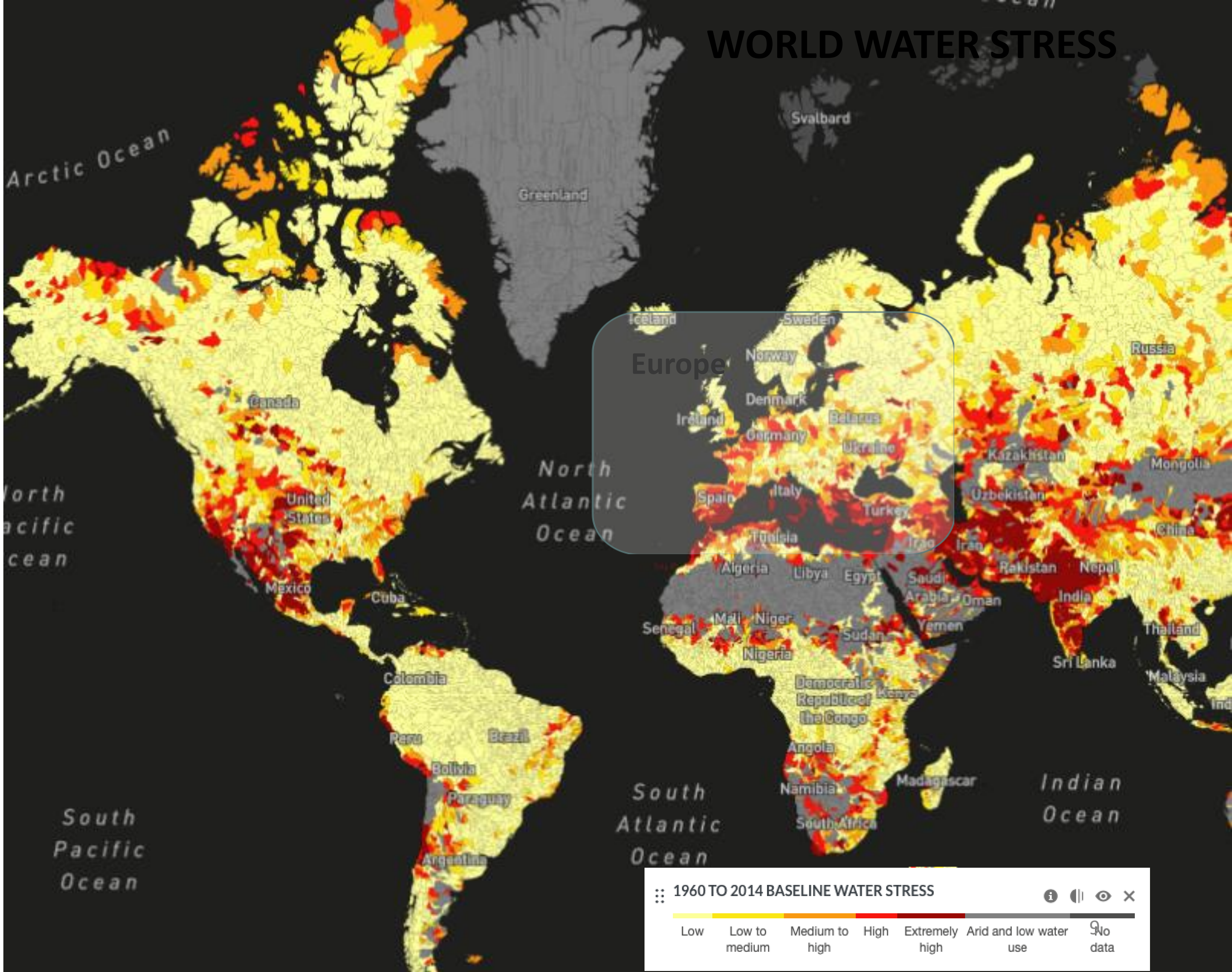
POPULATION GROWTH

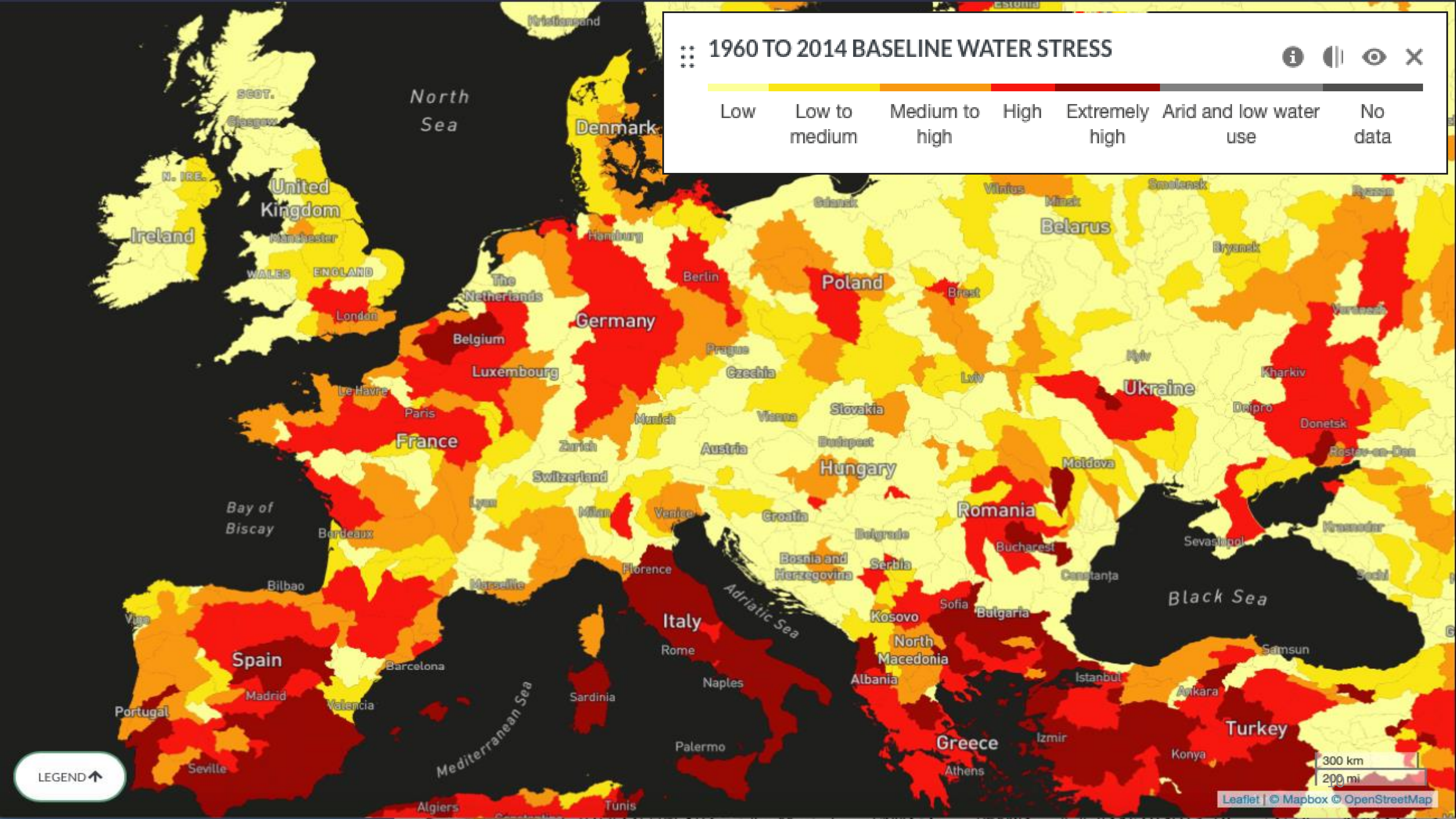


- MORE FOOD

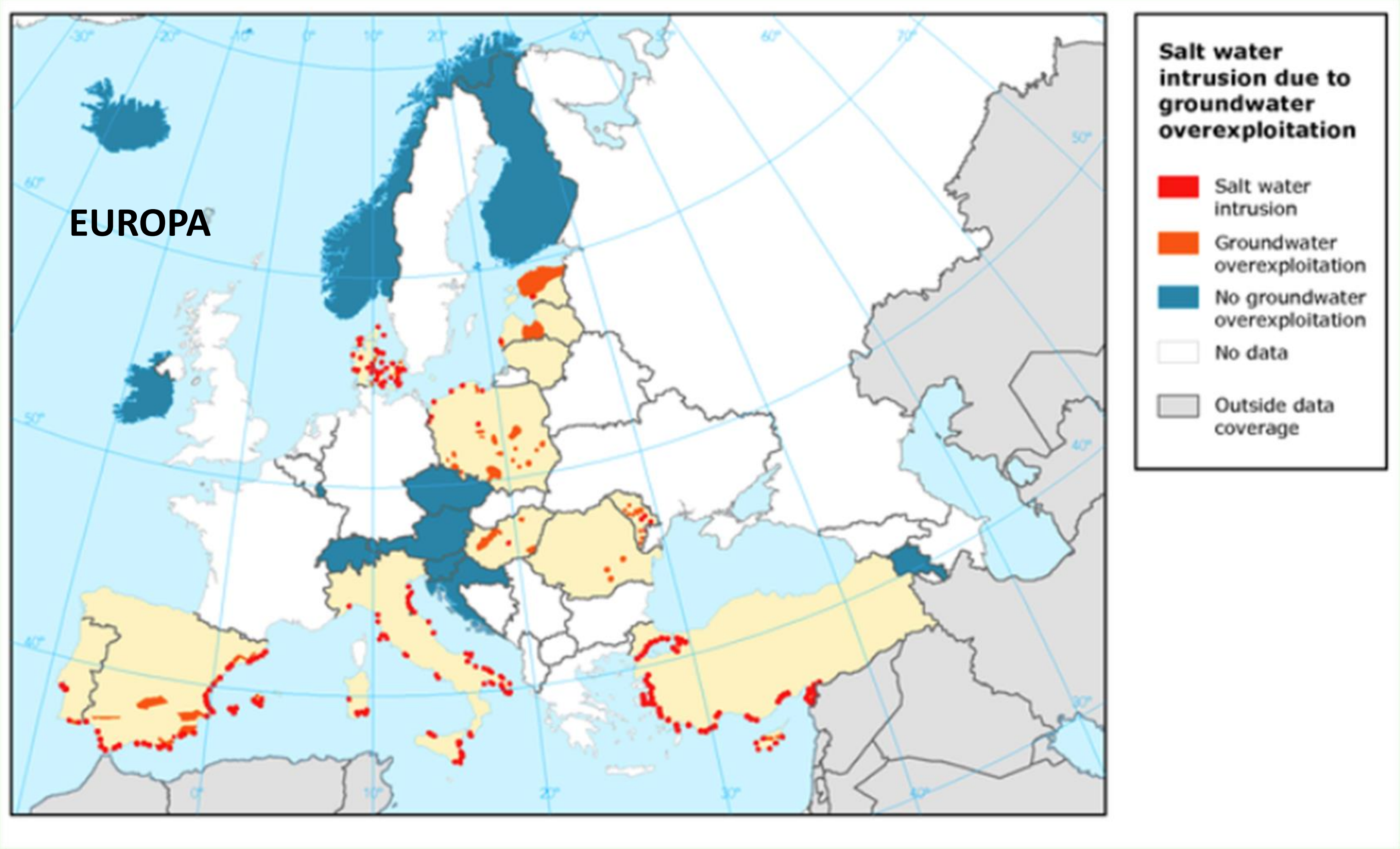
> MORE WATER

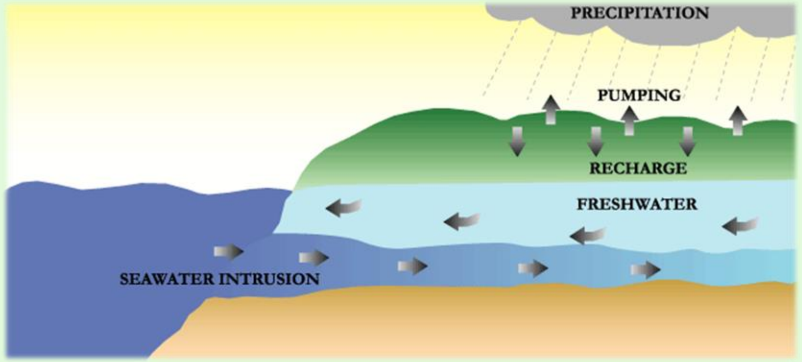
WORLD WATER STRESS

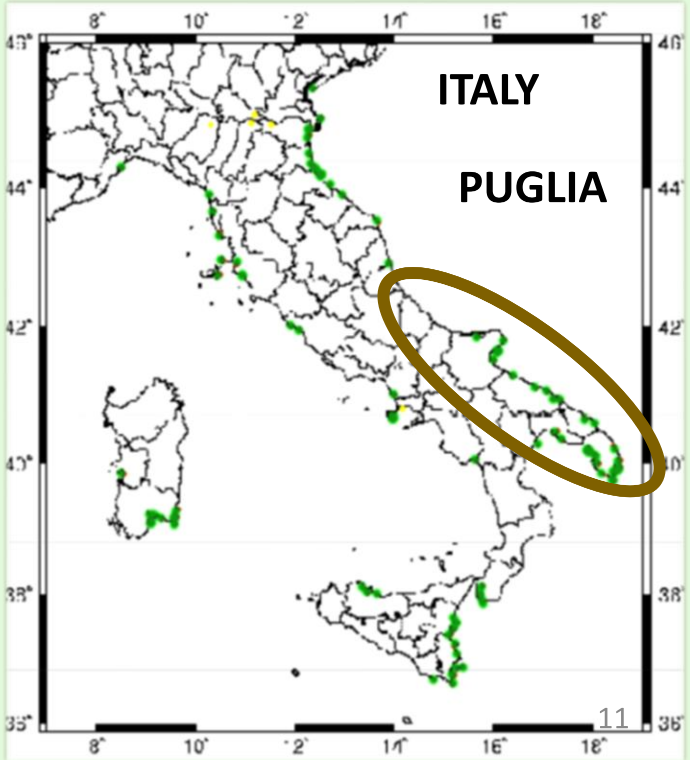



1960 TO 2014 BASELINE WATER STRESS
Low
Low to medium
Medium to high
High
Extremely high
Arid and low water use
No data
North Sea
Denmark
United Kingdom
Ireland
SCOT.
N. IRE.
WALES
ENGLAND
London
The Netherlands
Belgium
Luxembourg
Germany
Hamburg
Berlin
Poland
Belarus
Ukraine
Czechia
Slovakia
Austria
Hungary
Switzerland
France
Paris
Bay of Biscay
Bordeaux
Bilbao
Spain
Madrid
Barcelona
Valencia
Seville
Portugal
Italy
Rome
Naples
Palermo
Sardinia
Florence
Venice
Milan
Zurich
Munich
Vienna
Budapest
Croatia
Belgrade
Bosnia and Herzegovina
Serbia
Kosovo
North Macedonia
Albania
Romania
Bucharest
Moldova
Bulgaria
Sofia
Greece
Athens
Turkey
Istanbul
Ankara
Izmir
Konya
Samsun
Black Sea
Sevastopol
Kharkiv
Dnipro
Donetsk
Kyiv
Lviv
Brest
Minsk
Vilnius
Adriatic Sea
Mediterranean Sea
Marseille
Lyon
Le Havre
Algiers
Tunis
LEGEND
300 km
200 mi
Leaflet | © Mapbox © OpenStreetMap

SALT WATER INTRUSION







$EC_w \geq 3.0$ dS/m

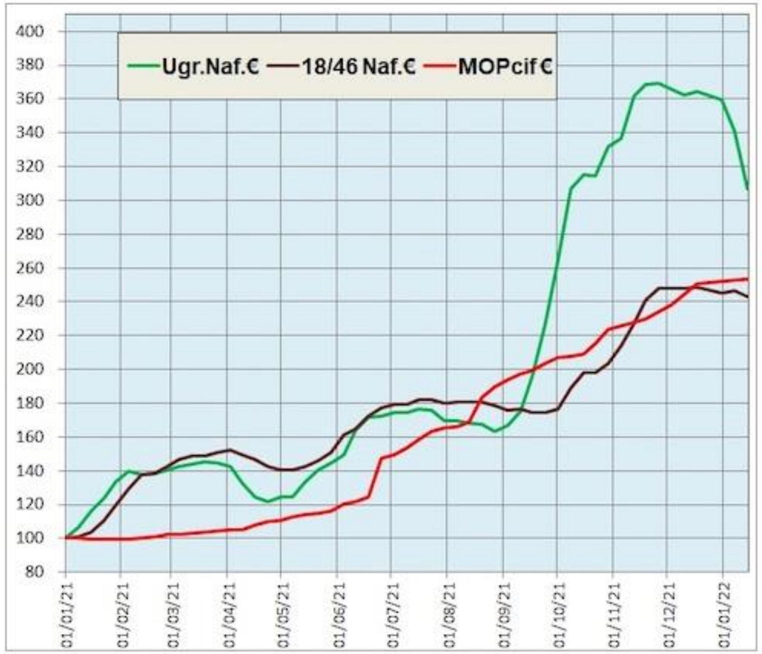
Fertilizer world demand

- nitrogen (N)
- phosphorous (P)
- potasssium (K)

the **global demand** for **fertilizers** is expected to grow annualy in an everage of 1.5-2.4 % from 2020 to 2050.

Table 4. World demand for fertilizer nutrient use, 2015-2020 (thousand tonnes)

Year	2015	2016	2017	2018	2019	2020
Nitrogen (N)	110 027	111 575	113 607	115 376	117 116	118 763
Phosphate (P_2O_5)	41 151	41 945	43 195	44 120	45 013	45 858
Potash (K_2O)	32 838	33 149	34 048	34 894	35 978	37 042
Total (N+ P_2O_5+K_2O)	**184 017**	**186 668**	**190 850**	**194 390**	**198 107**	**201 663**



Indice base 100 (gennaio 2021) dei prezzi internazionali valorizzati in €uro

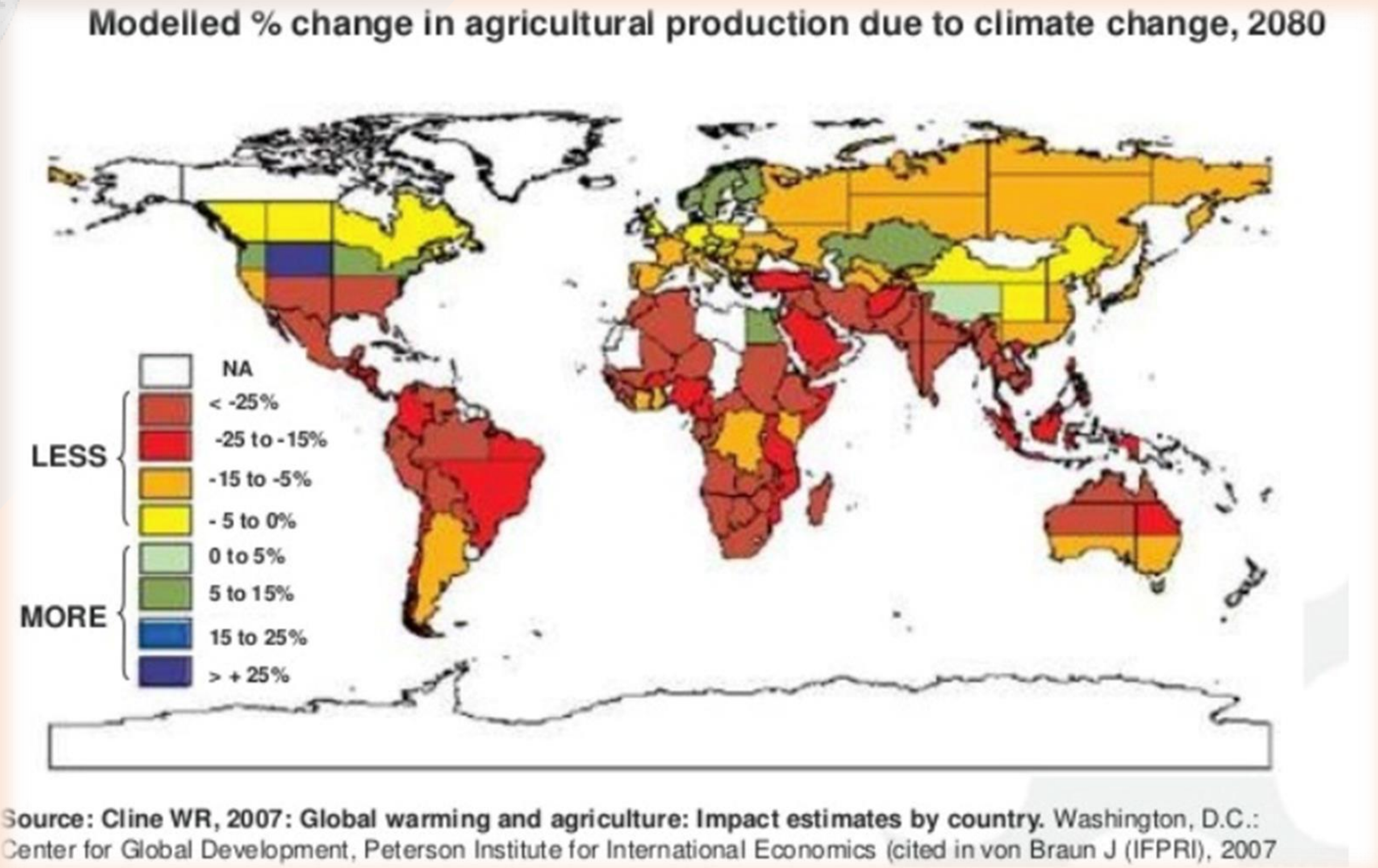
Legenda:Ugr.Naf=Urea granulare partenza Nord Africa; 18/46 Naf=fosfato biammonico partenza Nord Africa; MOPcif=cloruro di potassio porto europeo

FAO – Summary report 2017

INTRODUCTION

CLIMATE CHANGE

Climate change will probably increase the risk of food insecurity For example, South America may lose 1–21% of its arable land area, Africa 1–18%, Europe 11–17%, and India 20–40%.



+ EXTREME EVENTS

+ DRY PERIODS

LESS PRODUCTION

Introduction

Climate Change

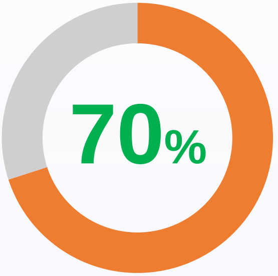
- Rapid Urbanisation
- Waste, pollution
- Deforestation
- Agriculture activities
- Industry
- Natural resources depletion

- Augmentation of T°
- Augmentation of oceans level
- Water crisis
- Soil degradation and deterioration
- Acidic rain
- Pathogenic diseases

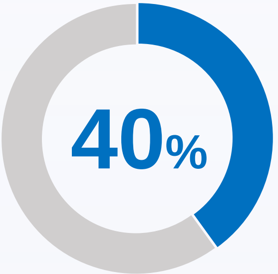
Nations Unies

LA BANQUE MONDIALE

Problem of wastewater in the world

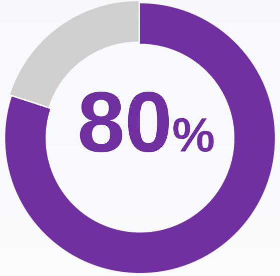


Total waste production in the world
3.4 Bt/year
in 2050

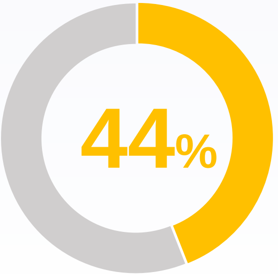


Waste dumped in Landfills

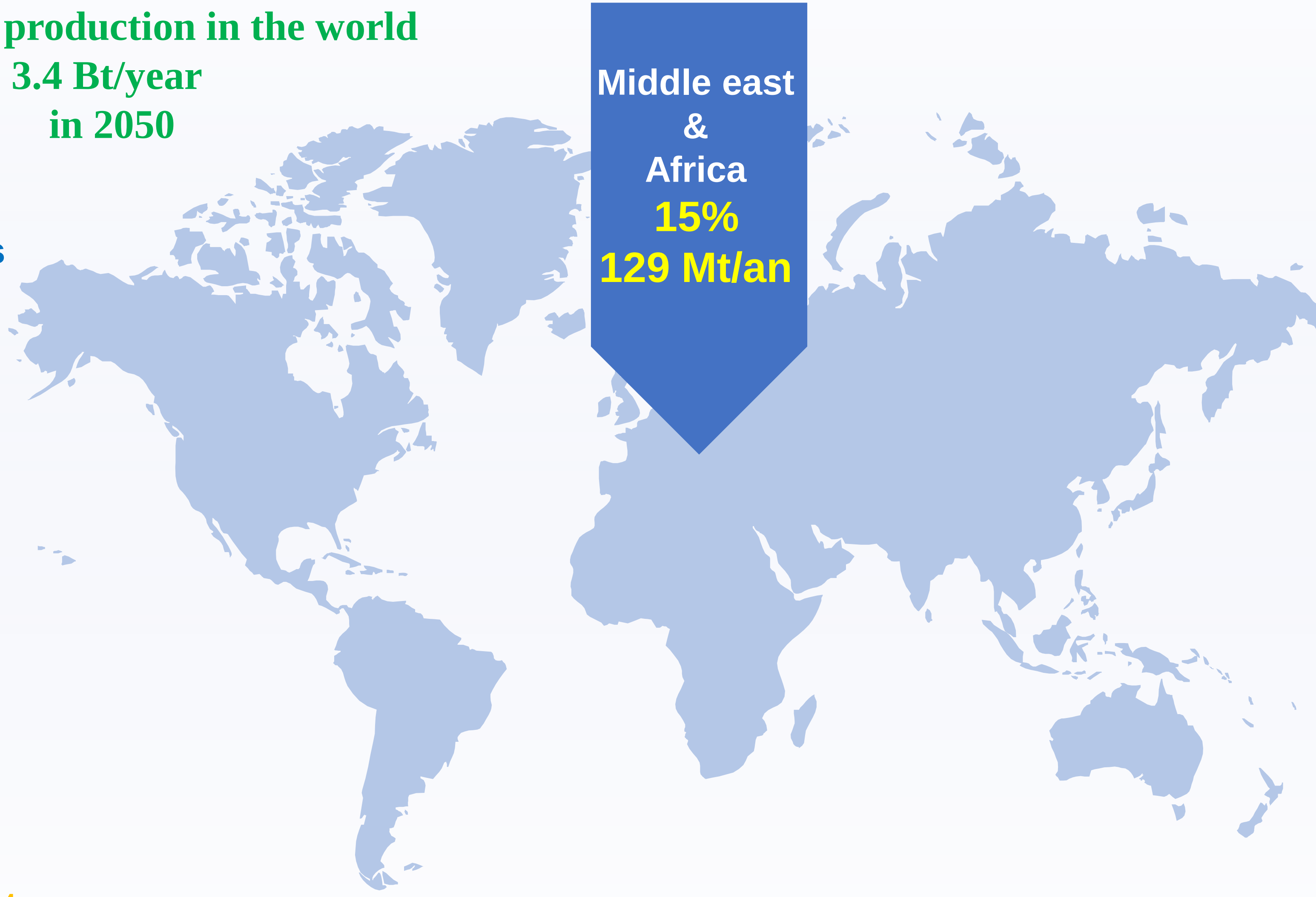
Treated or recycled wastewater

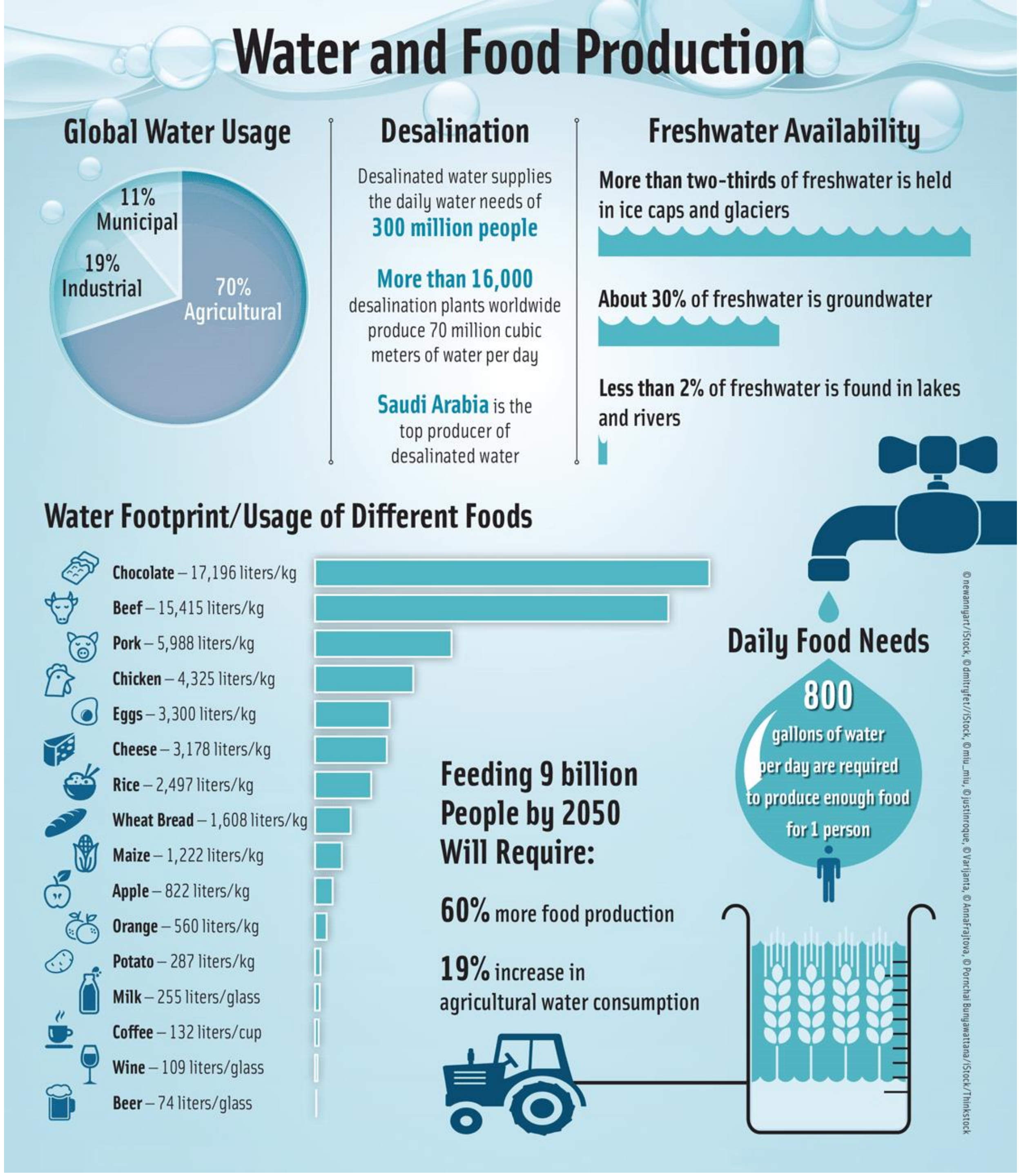


Untreated Wastewater



Organic waste





Water and Food Production
Global Water Usage
11% Municipal
19% Industrial
70% Agricultural
Desalination
Desalinated water supplies the daily water needs of 300 million people
More than 16,000 desalination plants worldwide produce 70 million cubic meters of water per day
Saudi Arabia is the top producer of desalinated water
Freshwater Availability
More than two-thirds of freshwater is held in ice caps and glaciers
About 30% of freshwater is groundwater
Less than 2% of freshwater is found in lakes and rivers
Water Footprint/Usage of Different Foods
Chocolate – 17,196 liters/kg
Beef – 15,415 liters/kg
Pork – 5,988 liters/kg
Chicken – 4,325 liters/kg
Eggs – 3,300 liters/kg
Cheese – 3,178 liters/kg
Rice – 2,497 liters/kg
Wheat Bread – 1,608 liters/kg
Maize – 1,222 liters/kg
Apple – 822 liters/kg
Orange – 560 liters/kg
Potato – 287 liters/kg
Milk – 255 liters/glass
Coffee – 132 liters/cup
Wine – 109 liters/glass
Beer – 74 liters/glass
Daily Food Needs
800 gallons of water per day are required to produce enough food for 1 person
Feeding 9 billion People by 2050 Will Require:
60% more food production
19% increase in agricultural water consumption

A Future-Proof Model for a Water-Smart Society

Across the EU, water shortages and droughts have increased dramatically in recent decades. They are likely to become more frequent and more severe in the future.

WATER SCARCITY AFFECTS

at least 11% of the European population

and 17% of the EU territory

Source: EC - Water Scarcity and Drought in the European Union

WATER SHORTAGES

have a severe impact on agriculture, industry and tourism.

When less water is available, the environmental impacts can be huge – there is too little water in rivers and lakes, wetlands dry out, and salt water may intrude into groundwater resources.

Mediterranean region

Around the Mediterranean*, some **20% of the population lives under constant water stress** and in summer, over 50% of the population is affected by water stress.

*Spain, Portugal, the Italian peninsula, Southern France, Cyprus, Greece and Malta

Source: EEA - Is Europe's freshwater use sustainable?

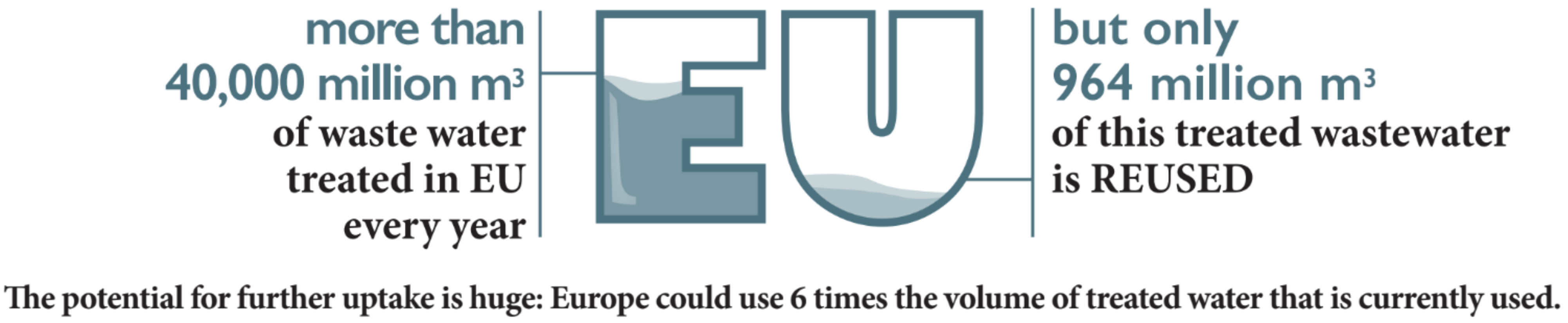
Water Scarcity

is no longer confined to a few corners of Europe, and is fast becoming a concern across the EU

By 2030

water stress and scarcity will probably affect half of Europe's river basins

A Future-Proof Model for a Water-Smart Society



Europe needs a supportive framework for water reuse

-In a circular economy, water reuse plays a key role, bringing significant environmental, social and economic benefits.

-There is high potential for increased water reuse but awareness of the benefits of this technology is low, and Europe lacks an adequate supportive framework for water reuse.

-Stronger regulatory and financial incentives could help Europe reuse more than 6,000 million m^3 of water every year by 2025.

The Water Europe vision for a Water-Smart Society

It projects a future of comprehensive **water security**, **sustainability** and **resilience** for all societal functions, and of full environmental protection.

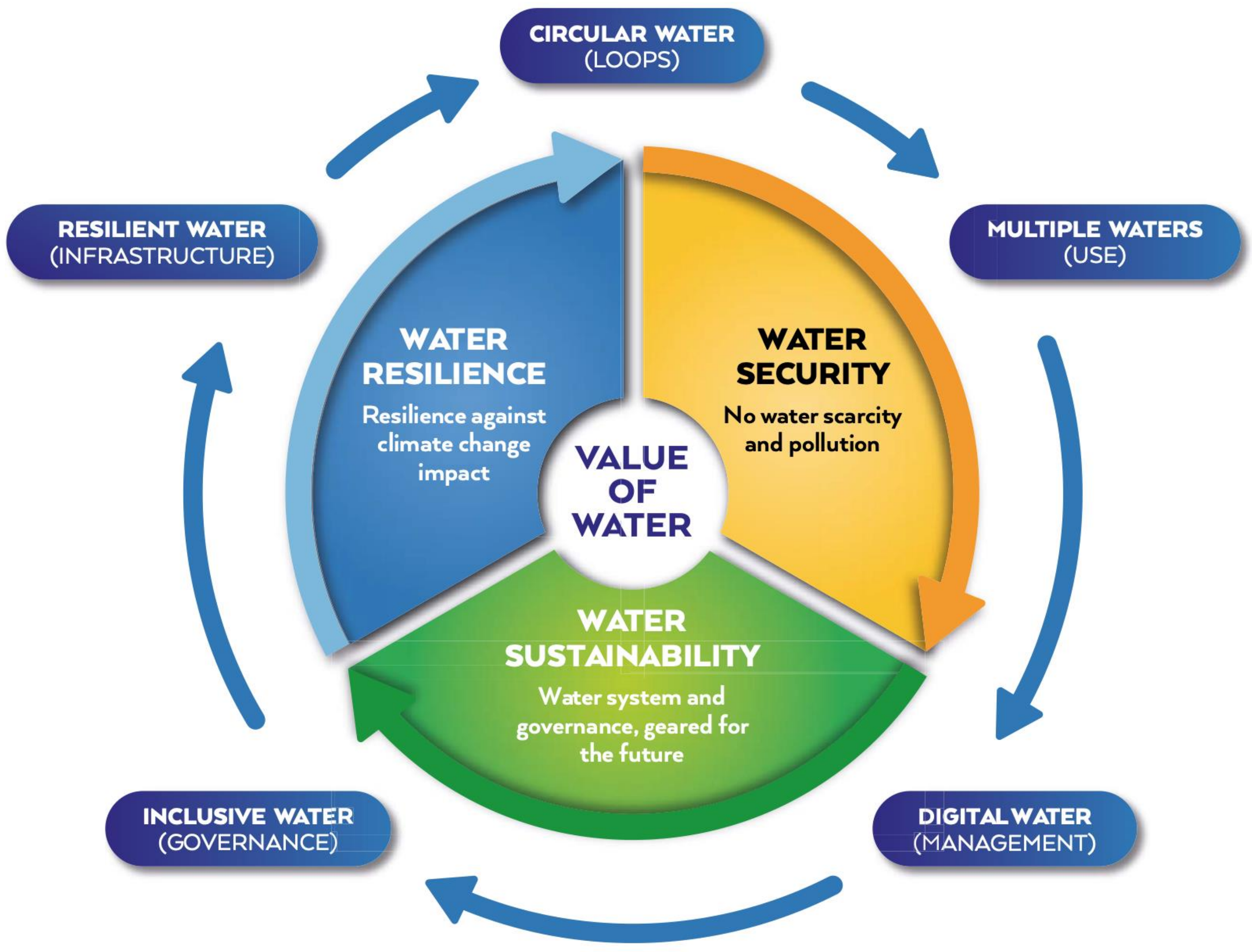
It is a vision in which all **relevant stakeholders are involved** in the sustainable governance of our water system, in a way that **meets ecological**, **social** and **economic needs**, without compromising the ability to meet these needs in the future;

Water scarcity and pollution of European **groundwater** and **surface water** are avoided, while **biodiversity** is restored;

Water, energy and resource loops are largely closed to foster a circular economy; the water system is resilient and robust against demographic pressure and climate change events;

European water-dependent businesses thrive, thanks to forward-looking research and innovation.

The Water-Smart Society Model



Source: Water Europe

The model consists of **one core value**, **three key objectives** that need to be achieved to realise the core value, and **five specific innovation concepts** that are crucial to realising the objectives. The model indicates how the innovation concepts and key objectives are interrelated, and together generate a 'flying wheel' effect that drives the process towards the Water-Smart Society.

Three key objectives

1. Water Security: safeguarding sustainable access to sufficient quantities of affordable and fit-for-purpose water, in order to preserve the health of the population and ecosystems, foster the socio-economic development of society, and ensure their protection against water-related disasters, such as those resulting from climate change.

2. Water Sustainability: ensuring water infrastructure, management and use that are economically and environmentally sustainable, in a way that meets current ecological, social and economic needs, without compromising the ability to meet these needs in the future.

3. Water Resilience: achieving long-term resilience, so that natural and anthropogenic water systems can withstand unexpected disruptive events, averting serious consequences, such as droughts and floods, while guaranteeing the reliability of the water system.

Five innovation concepts

1. Circular Water: circular water system that minimises water losses, captures and exploits the value in water, and fosters water security, sustainability and resilience.

2. Multiple Waters: incorporate a wide range of water sources and qualities (groundwater and surface water, rainwater, brackish water, brine, grey water, black water, recycled water) into a water-secure, resilient and sustainable water system.

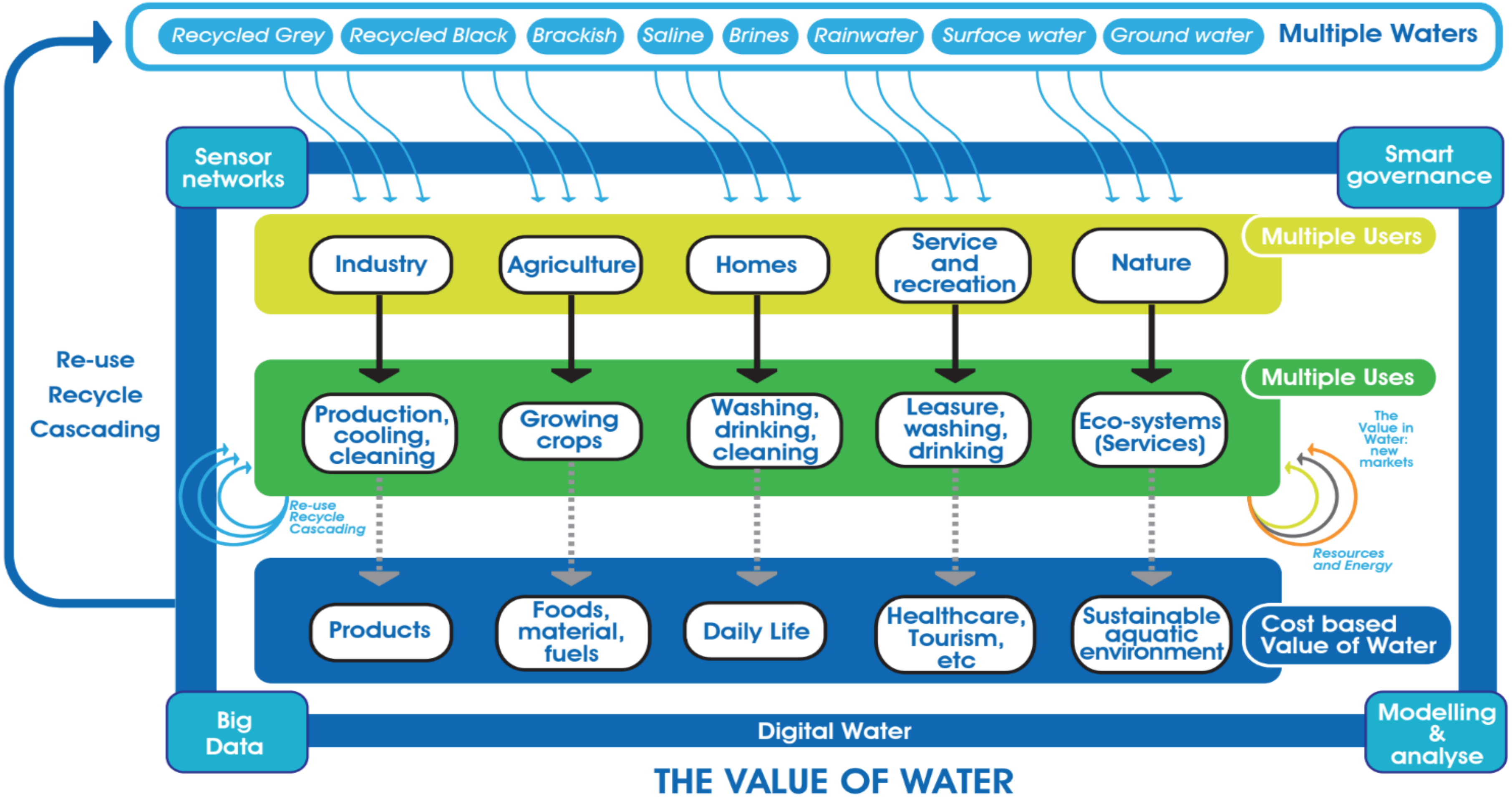
3. Digital Water: exploit the benefits of the extreme interconnectivity of people, devices and processes, and create capillary networks capable of monitoring the water system, starting at its multiple sources through to the individual end- user, thus generating continuous flows of valuable data for innovative decision-support systems at different governance levels.

4. Inclusive Water: establish a water system whose governance balances the interests of all stakeholders in its design, management and maintenance.

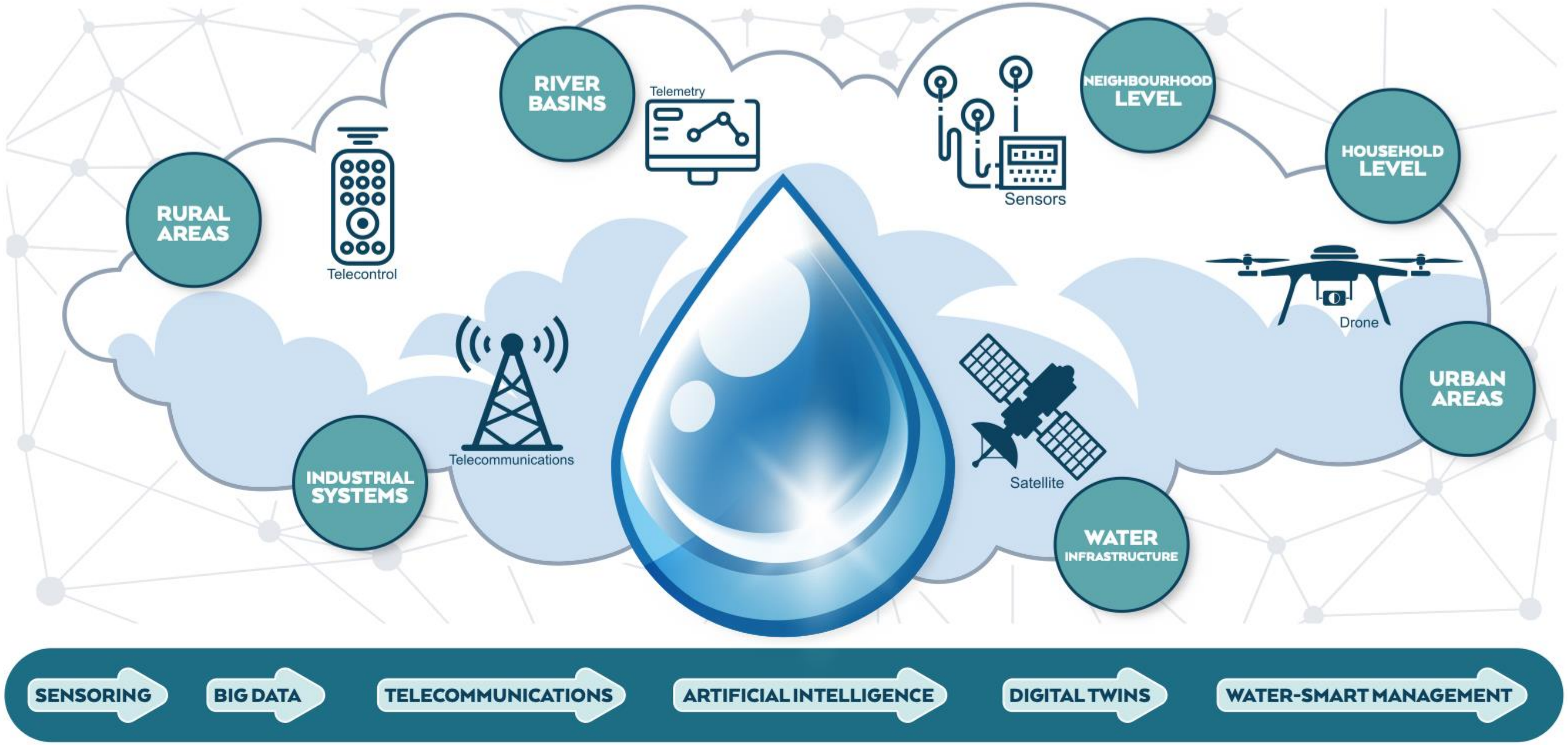
5. Resilient Water: create a resilient and reliable hybrid grey and green water system, designed to withstand severe external and internal shocks – such as climate-change induced floods and droughts – without compromising essential functions.

Transitioning to a Water-Smart Society

Water Europe envisions a European water sector that will be significantly transformed with respect to the current state of play. New concepts such as "Multiple Waters", "Digital Water" and "Hybrid Grey and Green Infrastructure", will drive the transition, decision makers and new water-smart economics. All will be enabled by new technologies developed within an open innovation environment and a completely redesigned water infrastructure to reach a circular economy system.



Transitioning to a Water-Smart Society



THE DIGITAL WATER PROCESS

1. BUSINESS SYSTEMS
- WATER-SMART MINDSET
- DESIGN OF EMBEDDED SYSTEMS
- WATER-ORIENTED LIVING LAB SETTING

2. INFORMATION SYSTEMS
- INTERNET OF EVERYTHING FOR WATER
- DATA ANALYTICS
- REMOTE SENSING, TELEMETRY, CONTROL & COMMUNICATION
- SCADA
- DIGITAL TWINS

3. ADVANCED CONTROL SYSTEMS FOR
- NETWORK MANAGEMENT
- OPTIMIZATION, PREDICTION AND DIAGNOSIS
- MICROSYSTEMS, SMART METERS SENSORS
- MODELLING, VIZUALISATION TOOLS, ARCHITECTURES

4. NETWORK COMMUNICATIONS
- REAL-TIME MONITORING
- EARLY WARNING
- DIGITAL SYSTEMS SERVICES
- SYSTEM'S HEALTH MONITORING

5. ASSET TECHNOLOGIES
- PROACTIVE OPERATIONAL RESPONSE
- PREDICTIVE ANALYTICS FOR MAINTENANCE, PROCESS OPTIMIZATION, INVESTMENT PLANNING
- BIM: BUILDING INFORMATION MODELLING, INCLUDING THE ENERGY AND WATER-USE, AND CIRCULAR MATERIALS COMPONENT

Source: Water Europe

Terms and Definitions

The Value of Water: **expresses the importance of water for our society at large, including enabling all our economic activities, societal functions related to health and well-being, as well as the (potential) economic value of resources (nutrients, chemicals, metals, minerals) and energy embedded in our water streams.**

The Value in Water: **indicates the economic and societal value that can be accomplished by extracting and valorising substances such as nutrients, minerals, chemicals and metals, as well as energy, embedded in used water streams.**

Water-Smart Society: **a society in which the true value of water is recognised and realised, and all available water sources are managed in such a way that water scarcity and pollution of groundwater are avoided.**

Water-System: **the combination of water infrastructure (grey and green), processes, governance mechanisms, rules and organisations related to the extraction, treatment, distribution, use and reuse of water, as well as the resilience of the water infrastructure.**

Hybrid Grey and Green Infrastructure: a combination of grey-engineered infrastructure, green engineered infrastructure and natural systems, part of the water system that will be used for water extraction, treatment, distribution, reuse and resilience.

Multiple Waters: an important concept underpinning the Water Europe water vision, picturing a future in which different alternative water sources and qualities (fresh ground and surface water, rainwater, brackish water, etc.) will be available in our society, and employed for various purposes by multiple users.

Digital Water: important concept underpinning the Water Europe vision, leading to capillary networks and sensors, meters and monitoring of the water system all the way along to the individual user, as such generating large amounts of valuable data (big data) for innovative Decision Support and Governance systems.

Water Europe Future-Proof Model for a Water-Smart Society: a model and framework that gives structure to the required research, development and innovations with respect to the current water system, in order to fulfil the vision of a "water-smart society".

Wastewater definition

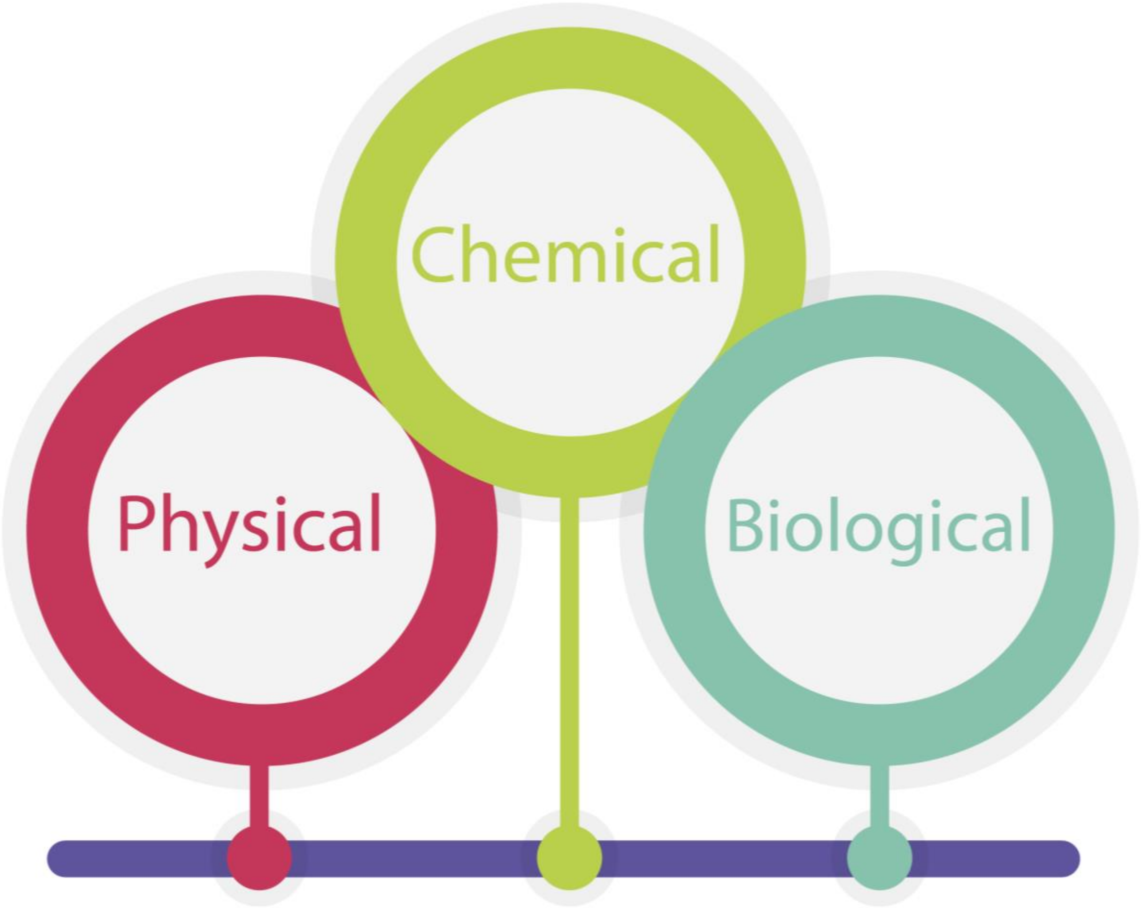
Wastewater is used water that has been affected by domestic, industrial and commercial use. The composition of all wastewaters is thus constantly changing and highly variable.

The composition of wastewater is 99.9% water and the remaining 0.1% is what is removed. This 0.1% contains organic matter, microorganisms and inorganic compounds. Wastewater effluents are released to a variety of environments, such as lakes, ponds, streams, rivers, estuaries and oceans.

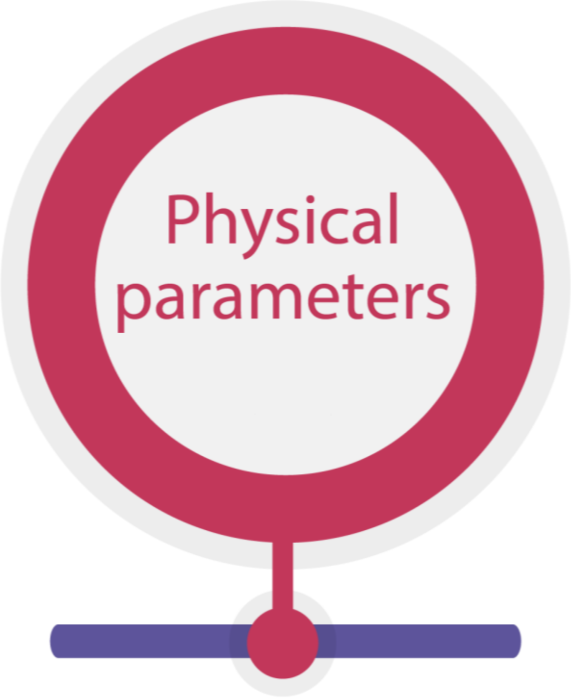
Wastewater quality and parameters

Depending on its source, wastewater has peculiar characteristics. Industrial wastewater with characteristics of municipal or domestic wastewater can be discharged together. Industrial wastewater may require some pretreatment if it has to be discharged with domestic wastewater. The characteristics of wastewater vary from the origin source.

In general, the contaminants in wastewater are categorized into physical, chemical and biological parameters.



Wastewater quality and parameters



- **Electrical Conductivity (EC):** This parameter is a general indicator of water quality, especially a function of the amount of dissolved salt, and can be used to monitor processes in wastewater treatment that causes changes in total salt concentration and thus changes the conductivity. The variation of conductivity in the wastewater can be caused by variations in the ion content. The unit of EC is S/m.

- **Total Dissolved Solids (TDS):** refers to any minerals, salts, metals, cations, or anions dissolved in water. TDS comprise inorganic salts, principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates, and some small amounts of organic matter that are dissolved in water. TDS is expressed in mg/l.

- **Total Suspended Solids (TSS):** refers to waterborne particles that exceed 2 microns in size. Any particle that is smaller than 2 microns, on the other hand, is considered a TDS. The majority of total suspended solids comprise of inorganic materials; however, algae and bacteria may also be considered TSS. TSS could be anything that floats or "suspends" in water, including sand, sediment, and plankton. TSS is expressed in mg/l.

Wastewater quality and parameters

Chemical parameters

- **Dissolved Oxygen (DO):** The oxygen content (mg.L) in water will decrease when there is an increase in nutrients and organic materials from industrial wastewater, sewage discharges, and runoff from the land. (Intensive land uses such as farming produce more nutrients in runoff than native forest.) Excessive plant and algae growth and decay in response to increasing nutrients in waterways can significantly affect the amount of dissolved oxygen available.

- **Biochemical oxygen demand (BOD):** BOD is a measure of the amount of DO required by aerobic microorganisms to decompose organic matter present in a sample of water at a certain temperature over a studied period. BOD value is usually expressed in milligrams of oxygen per liter of water (mg/L).

- **Chemical oxygen demand (COD):** COD is a measure of the oxygen equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant. COD is widely used as a measure of the susceptibility to oxidation of the organic and inorganic materials present in water bodies and in municipal and industrial wastes.

Wastewater quality and parameters

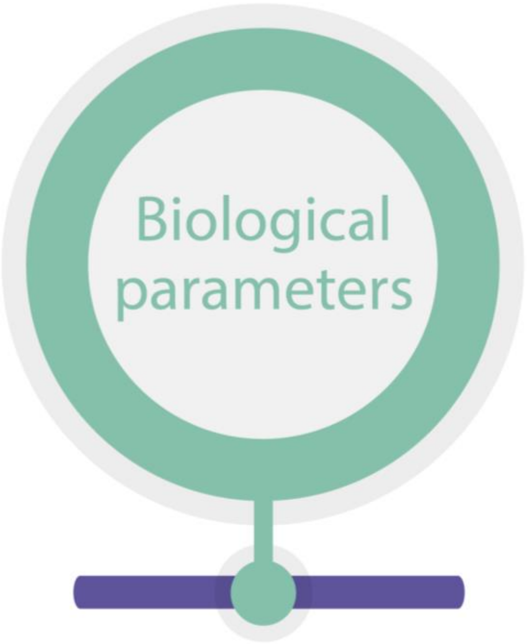
- **Total Organic Compound (TOC):** TOC is a measure of the total amount of carbon in organic compounds, or contaminants, found in a liquid. Most often, it is used to measure water quality or cleanliness of pharmaceutical manufacturing equipment. By using TOC analysis, companies are able to check that the water they are using is pure enough for their process.

- **Ammonium (NH4-N) and nitrate (NO_3-N): NH4-N** is an inorganic nitrogen compound which arises from the biological degradation of organic nitrogen compounds. Ammonium can be converted into **NO_3-N** by adding oxygen (nitrification). In the aquatic environment, nitrification causes high oxygen consumption.

- **Total Kjeldahl Nitrogen (TKN):** TKN is a parameter used to measure organic nitrogen and ammonia. The TKN content of influent municipal wastewater is typically between 35 and 60 mg/L. Organic nitrogen compounds in wastewater undergo microbial conversion to **NO_3-N** and ammonium ion **NH4-N**.

- **Total-P:** Total-P is a measure of all phosphorus found in a sample, whether that P is dissolved or particulate. This is commonly used when sampling in wastewater treatment, and is notably used to determine the quality of water.

Wastewater quality and parameters



- **Total coliforms (TC):** Coliforms are a group of bacteria found in plant material, water, and soil. Water systems test for indicator organisms, like coliforms, to check for possible contamination by biological pathogens. Most coliforms are not harmful, but they come from the same sources as other bacteria and organisms that could make a disease. A positive coliform test means possible contamination and a risk of waterborne disease.

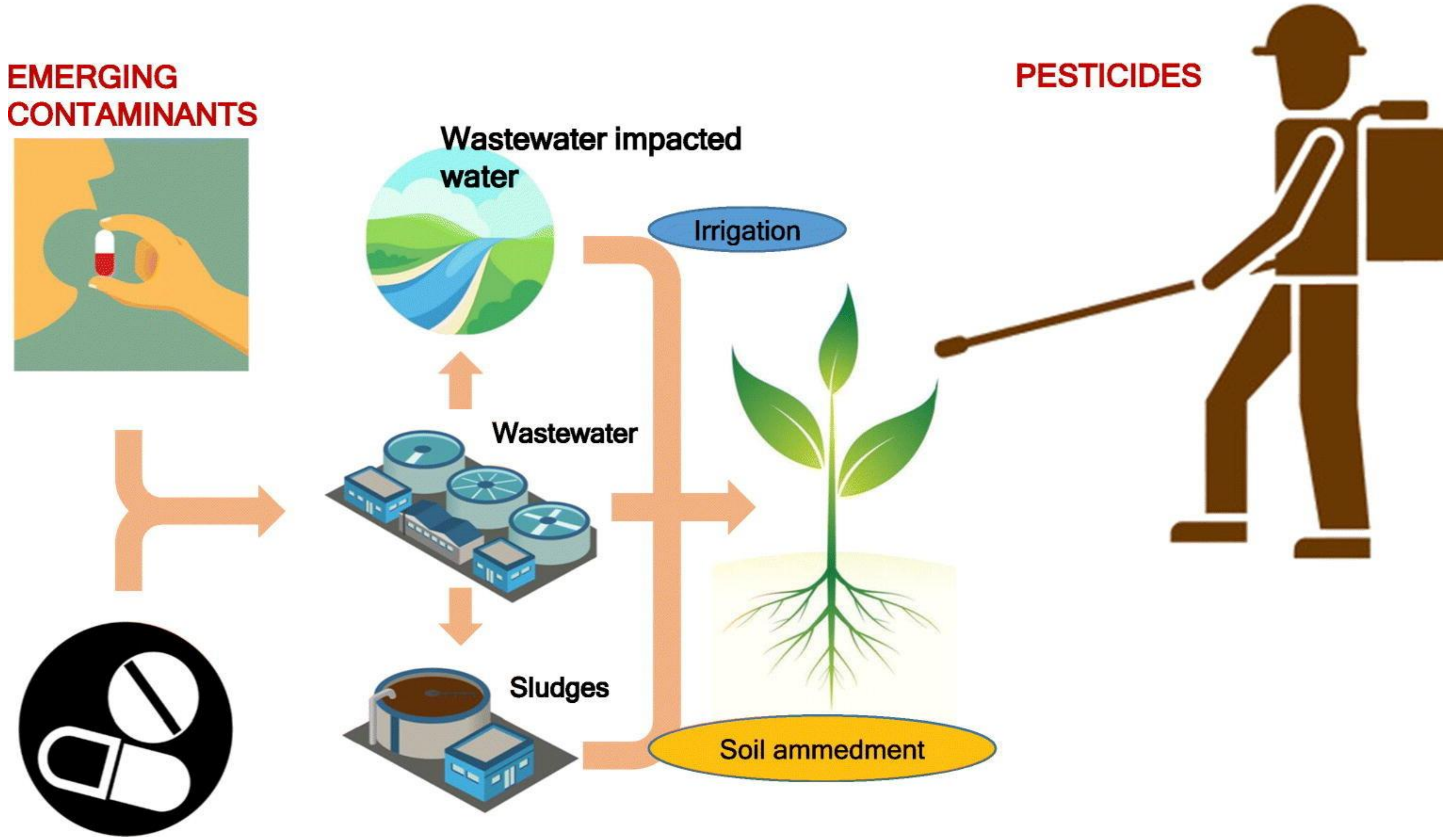
- **Faecal coliforms (FC):** are one type of coliform bacteria that is found mainly in animal digestive tracts and feces. Fecal coliforms are a more specific indicator of fecal contamination of water.

- **E. coli (Escherichia coli):** is a species of fecal coliform bacteria. *E. coli* almost always comes from animal feces. E. coli is considered the best indicator of fecal water contamination. If E. coli is present, harmful bacteria or other pathogens may also be present.

- **Helminth:** Helminths are large macro-parasites or parasitic worms that are contained and transmitted through wastewater.

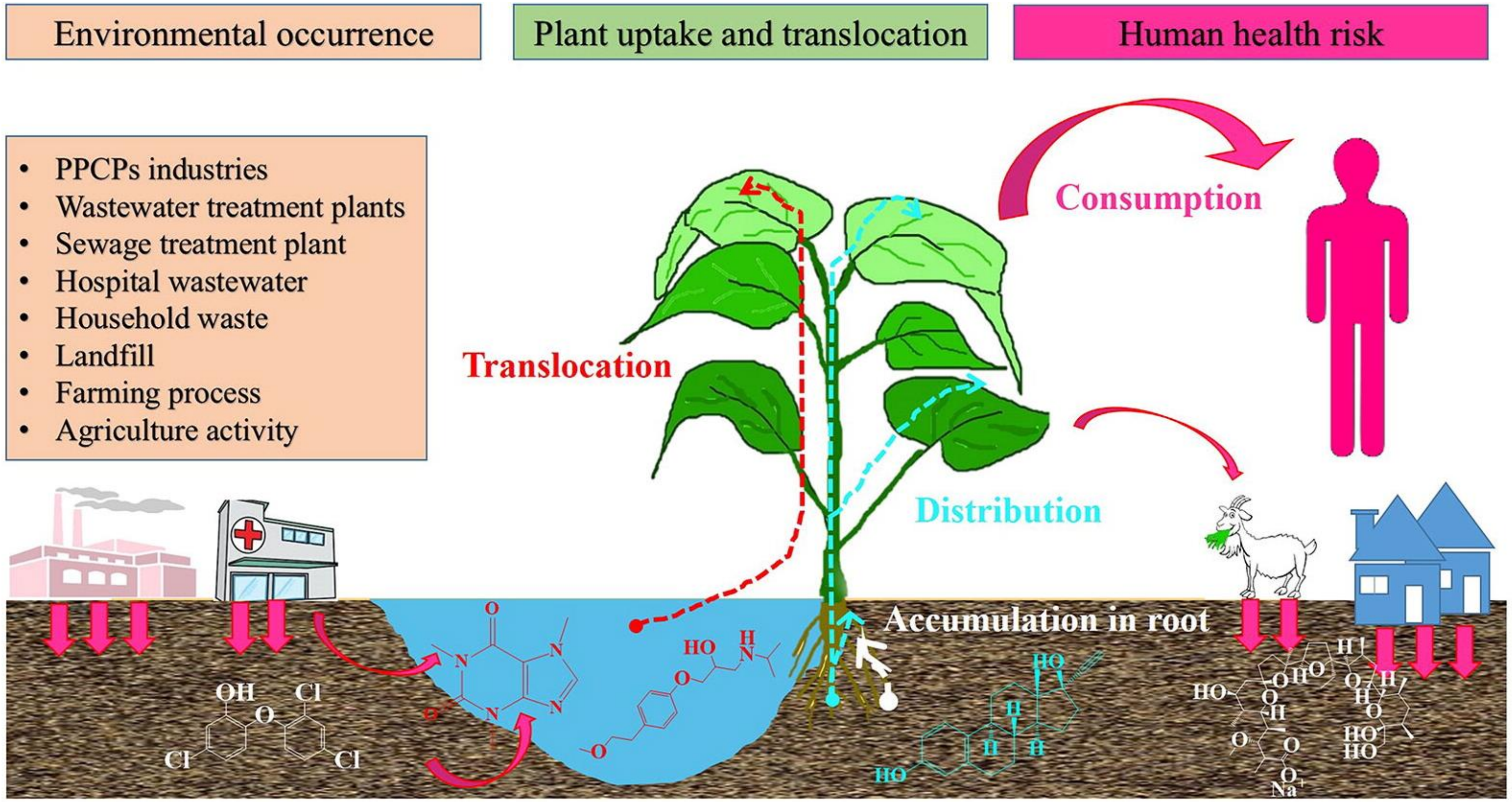
Wastewater emerging contaminants (ECs)

ECs originate from a variety of product types including human pharmaceuticals, veterinary medicines, nanomaterials, personal care products, paints and coatings. Some ECs, such as the natural toxins and degradation products of man-made chemicals may also be formed within the natural environment by animals, plants and microbes.



Wastewater emerging contaminants (ECs)

ECs will be released to the agricultural environment via a number of routes. Veterinary medicines and their metabolites will be released directly to soils (animals at pasture) or indirectly when manure and slurry from intensive livestock facilities is applied to agricultural land as a fertilizer. Human pharmaceuticals and personal care products will be released through the application of sewage sludge (biosolids) to land or from irrigation with wastewater effluent. Other ECs may be formed in the environment itself.



Wastewater emerging contaminants (ECs)

Routes of input of ECs to wastewater reused in agriculture

Emerging contaminant class	Route of input to agricultural systems	Other sources to the environment	Relative importance of agricultural sources in terms of water contamination
Natural toxins	Release from plants, algae and fungi	NA	High
Veterinary medicine	Direct release to soils from animals at pasture; application of contaminated manure and slurry to land	Use in aquaculture; manufacturing releases; disposal of containers	High
Hormones	Direct release of natural and synthetic hormones by animals at pasture; application of manure and slurry to land	Application of sewage sludge, containing natural and synthetic hormones arising from the human population	High – hormonal substances arising from animals Low – hormonal substances arising from the human population
Transformation products	Produced from man made chemicals that are applied directly to agricultural systems or in activated sludge/irrigation water	Formed in wastewater treatment processes	Dependent on the nature of the parent compound: High (TPs of veterinary medicines) Low (TPs of pharmaceuticals, personal care products etc.)

Wastewater emerging contaminants (ECs)

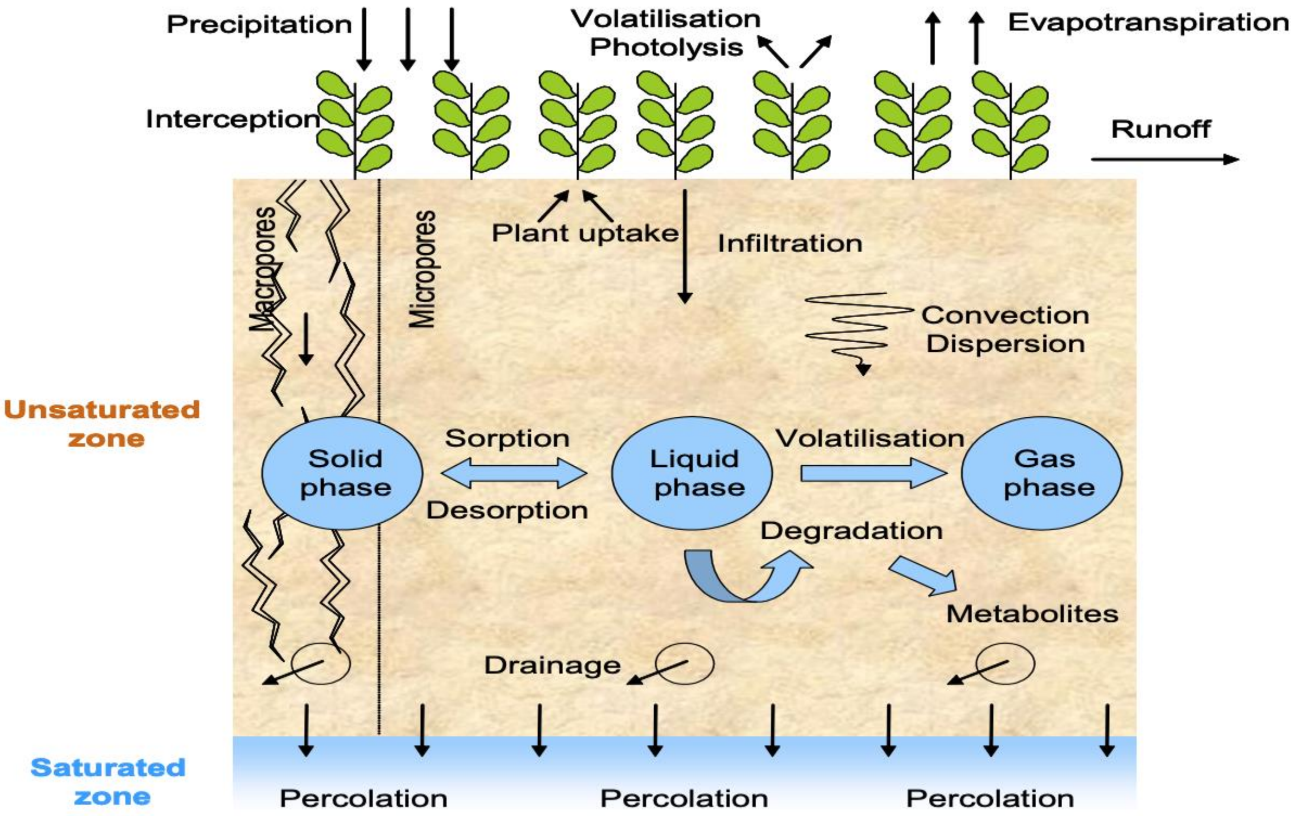
Routes of input of ECs to wastewater reused in agriculture

Emerging contaminant class	Route of input to agricultural systems	Other sources to the environment	Relative importance of agricultural sources in terms of water contamination
Emerging persistent organic pollutants (e.g. flame retardants)	Application of sewage sludge to agricultural land as a fertiliser; irrigation with wastewater or contaminated surface water	Emissions to surface waters from wastewater treatment plants	Low
Human medicines	Application of sewage sludge to agricultural land as a fertiliser; irrigation with wastewater or contaminated surface water	Emissions from wastewater treatment plants; disposal of unused medicines to landfill; manufacturing releases	Low
Nanomaterials	Application of nanopesticides to crops; release of nanomedicines by livestock; application of sewage sludge to agricultural land as a fertiliser; irrigation with wastewater or contaminated surface water	Emissions from wastewater treatment plants; disposal of waste to landfill; manufacturing releases	Currently low as nanomaterials are mainly used in personal care products and paints and coatings Importance could increase in the future as the nanopesticide and nanomedicine markets develop.
Bioterrorism/sabotage agents	Sabotage of crops and livestock	Chemical incidents in cities	Has the potential to be high (depending on the agent)
Human personal care products	Application of sewage sludge to agricultural land as a fertiliser; irrigation with wastewater or contaminated surface water	Emissions to surface waters from wastewater treatment plants	Low

Wastewater emerging contaminants (ECs)

Uptake into biota

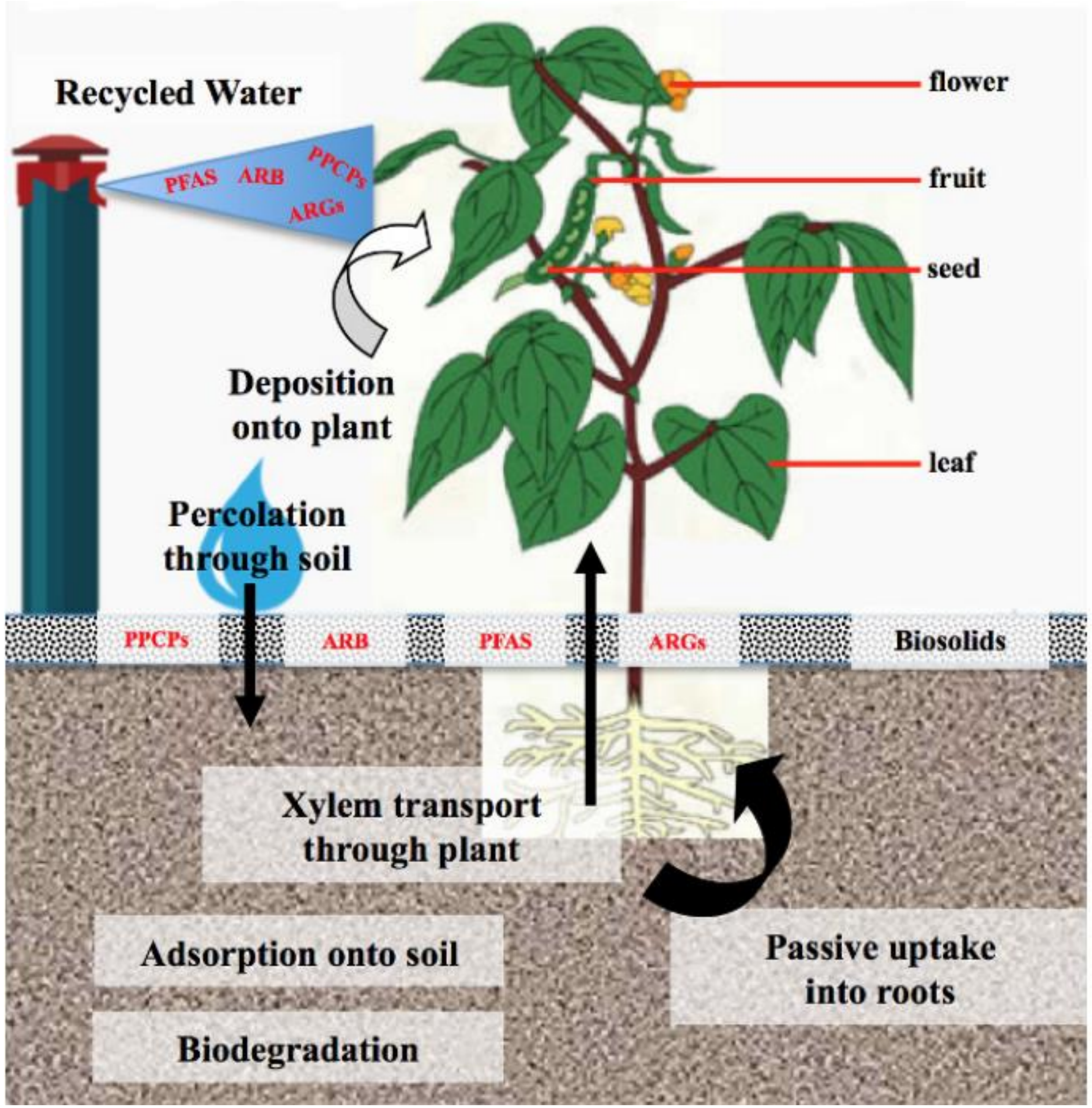
The EC may be degraded by biological, physical or chemical processes, it may stick to soil particles, it may be taken up by plants, it may leach to groundwater or it may be transported to surface waters through runoff and drainage water. The extent to which any of these processes happens will depend on the underlying physical properties of the EC (including how soluble it is in water solubility; how attracted the EC is to organic matter and other soil components; and how volatile the substance is) as well as the properties of the soil and the climatic conditions.



Wastewater emerging contaminants (ECs)

Uptake into biota

Studies with a range of veterinary medicines showed that a number of antibiotics are taken up by plants following exposure to soil at environmentally-realistic concentrations of the compounds whereas other compounds were not observed to be accumulated. Less work has been done on human pharmaceuticals but recent studies have shown that the antidepressant compound fluoxetine be accumulated by brassicas. The factors affecting the uptake of ECs into plants are poorly understood and this is an area that needs much more research.



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Thank you for your attention

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