Water: The Big Picture

> *"All praise be yours, my Lord, through Sister Water,*
> *So useful, lowly, precious and pure".*
> *St. Francis of Assisi, Canticle of Creatures*
>
> *"The heavens and the earth were joined together*
> *… then We clove them asunder, and made from water*
> *every living thing"*
> *The Holy Koran 21.30*

Earth is full of water. There is about 1.5 billion km^3 of it, so much that it covers 70% of our planet's surface. It's an enormous amount but it diminishes dramatically as far as the available water for human use is concerned. Nearly 97% of the whole of the water on Earth (see chart 1) is actually in the oceans and salty. The other 3% is freshwater, but three fourths of it are trapped in iced poles and the remaining almost entirely flows deeply underground, becoming accessible only when it comes out in rivers or stores in lakes. So the actual figure for water that is "readily available" for human beings is just the 0.003% of the total volume. In other words, given that the total water on the globe could fit into a 100 litres barrel, the available quantity could at most fill a coffee spoon.

Water resources on the globe **1**

Estimates of global water resources vary depending on different calculation methods

	Volume (thousand km3)	% of total volume
Ocean	1.338.000,00	96,5%
Groundwater (gravity and capillary)	23.400,00	1,7%
Predominantly fresh groundwater	10.530,00	0,76%
Soil moisture	16,50	0,001%
Glaciers and permanent snow cover	24.064,00	1,74%
Water in lakes*	176,40	0,013%
Marshes and swamps	11,50	0,00%
River water	2,12	0,0002%
Biological water	1,12	0,00%
Water in the atmosphere	12,90	0,001%
Total volume in the hydrosphere	1.386.000,00	100,00%
Total freshwater	35.029,20	2,53%

* Freshwater for 91,000 km3 and salt water for 85.4 km3.

Source: UNESCO

A coffee spoon that, at least in theory, could nevertheless be sufficient to cover the need for water of human population. At the end of the last century annual use of water was split into 150 km^3 for domestic use, 200 for industry and 2,500 for agriculture. Needs that should be certainly met with the "asset" of water flow of about 40,000 km^3, returned available every year through the hydrological cycle. In fact until recently the perception that water is abundant on Earth has been prevailing. So much that Adam Smith – quite an expert on "exchange values" – was led to write in his "Paradox of Diamonds and Water" that "Nothing is more useful than water: but it will purchase scarce anything; scarce anything can be had in exchange for it." This was, Smith argued, the consequence of the fact that – contrary to what happens with diamonds - water is abundant and accessible to everybody. Thus, the conclusion was that although essential to life, it was impossible to give water any exchange value.

However, the abundance of water – and in recent years as well the perception of it - has been progressively fading with a trend that has been dramatically accelerated in the last 50 years. In 1950 each human being had a potential annual availability of water of 17,000m^3. Today it dropped to just 6,600 and estimates point to 4,800 in 2025.

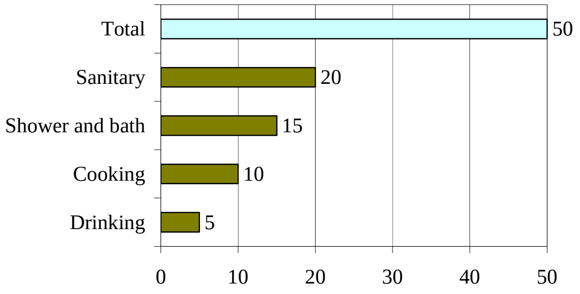
This is because of the combination of two phenomena: on one side the increase in water consumption mainly due to the demographic progression, and on the other side the drop in quantity of "readily available" water, mainly caused - directly or indirectly, through the impact humans have on the hydrological cycle - by pollutions generated by anthropic activities.

Given the highly irregular distribution of water both across the continents and during the different months, if we let things develop according to the current trend, it would only take 20 years to end up with 3 billion of people without the so called "**minimum water supply**" (see chart 2). At that point it would be virtually impossible avoiding wars to gain access to the "Blue Gold", something that is already happening nowadays with almost 50 conflicts risen between nations for causes related to the right of use and exploitation of water resources.

To counter this trend there are ongoing discussions to redefine the legal status of water: no longer *res nullius* as from tradition, but – acknowledging its importance – an asset for the whole of the human beings. Access to water, especially to drinking water, would therefore become an unconditional human right to be guaranteed to everybody regardless of race, age, gender, social class, revenue, nationality, religion or local availability..

Minimum water supply **2**

liters, Daily minimum use of water per a single person is estimated around 50 liters.



Source: Basic Water Requirements for Human Activities: Meeting Basic Needs by Peter H. Gleick, M. IWRA - Pacific Institute for Studies in Development, Environment, and Security

This picture calls for urgent and inevitable actions to pursue through the use of technology the increase of availability of water, not only for drinking, washing, cooking but also for agricultural and industrial utilization. As a matter of fact, these two human production activities (see Report -Agriculture's great thirst), essential to our life, now significantly absorb enormous quantity of water and cause stress on water resources which - especially if drinkable - should be dedicated to human consumption. Regarding this, some of the most promising technologies, that could one day really "make the difference" are:

- Desalination
- Treatment and use of wastewater
- Recovery and recycle of rain water

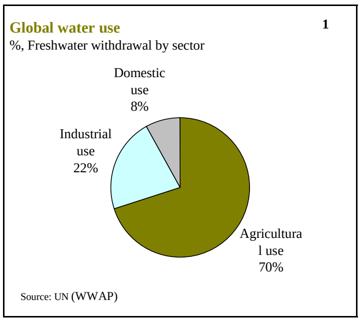
Stefano Gulmanelli

Agriculture's great thirst

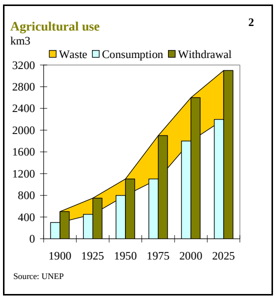
One day, every last drop of water which drains into the whole valley of the Nile... shall be equally and amicably divided among the river people, and the Nile itself ... shall perish gloriously and never reach the sea.. *Winston Churchill, 1908*

No technological innovations of harvesting and production of water can have more decisive impact on the level of Earth's water resources for human use than developments of technologies and methods of farming which require less consumption of water than it is actually applied globally.

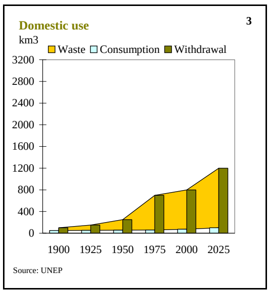
70% of water is used for agriculture (see chart 1) whose great part is in the form of irrigation. The quantity absorbed by agriculture (see chart 2) has kept increasing (so did the loss by unreliability and inefficiency of infrastructure and irrigation processes) although it is not as fast as the "domestic use" (see chart 3) which is tripled from 1950.


Global water use 1
%, Freshwater withdrawal by sector

Source: UN (WWAP)


Agricultural use 2

Source: UNEP


Domestic use 3

Source: UNEP

To get an idea how much agriculture stresses on the world water capital, it is enough to think that today it takes 2,000 litres of water to produce the average daily necessary intake of food for a single person. In less efficient situations as we see in China or India a ton of grain "drinks up" one thousand tons of water. In any case, most common crops and livestock are at water intensive (see chart 4).

How much water is needed to grow different crops? **4**

Crop/Food	kg water per kg food
Potato	500 to 1500
Wheat	900 to 2000
Alfalfa	900 to 2000
Corn	1000 to 1800
Rice	1900 to 5000
Soybeans	1100 to 2000
Chicken	3500 to 5700
Beef	15000 to 7000

Source: The World's Water: The Biennial Report on Freshwater Resources, by Peter H. Gleick (Island Press, Washington, D.C.)

These figures suggest that the leverage of the greater potentiality to release water resources for man and for other animals on the planet would be that of increase of efficiency of irrigation system. (Let's put aside the alternative way for genetic "construction" of agricultural species of low water consumption. It is possible but controversial, too.) A mere improvement of 10% of efficiency of irrigation system in the Indian Planes in Pakistan could supply water to cultivate another 2 million hectares of lands. And above all, a reduction of 10% of world irrigation requirement would mean doubling of availability of water for domestic use.

When water is scooped from aquifers to be conveyed to the crops, the substantial amount is lost in two ways: firstly the parts of such water never reach to cultivated lands because canal facilities are bad, tubes run off or simply vaporization "assures" a prime significant loss of precious resources on the road and always exits from the hydrological cycle (partly it comes back but if so, it's even worse, because the quality could be deteriorated by insecticides or salts stripped from the passed land). When water arrives to the fields to be irrigated, it is usually distributed by gravity (canals and gutters) or by pressure (sprinklers). In both cases, the former more than the latter, the share of water reaches to roots of plants is much less than initially transported to the irrigated land. Two innovative techniques allow to reduce the gap as far as we can almost ignore it (not by chance they're called "freshwater augmentation techniques"):

The so called "**drip irrigation**" creates a network of porous and pierced tubes which release water only close to roots of cultivated plants. It brings efficiency of 95%, especially if the tubes are underground and avoid evaporation. It lowers the use of water to 45-60% compared to the normal gravity system. Today this system is adopted for 1% of the irrigated lands in the world (that are 20% of the cultivated lands). This system is expected to have an enormous potentiality of improvement. Some countries have chosen it the preferred irrigation method. Israel uses it for more than half of its irrigated lands.

LEPA (low-energy precision application) is a pressure system that however doesn't spray in the air but near the ground to be irrigated. The necessary pressure is lower and the energy costs can be decreased. Above all it assures efficiency of around 90%.

The fact is that both dripping and LEPA have implementation costs that are often difficult to be afforded by the developing countries, in which scarcity of water is an acute problem per se.

In these situations the solution can by given – as it already happens in agricultural areas next to big urban centres like Mexico City, Asmara in Eritrea and in more than 15 different countries for around 1 million hectares all together – by a centuries – old practice, brought back to nowadays use by the increasing emergency of the situation and the advent of new technologies for treatment: the use of urban wastewater (see Report –Membrane versus wastewater).

Stefano Gulmanelli

Desalination

'Water, water, every where,
And all the boards did shrink;
Water, water, every where,
Nor any drop to drink'.
"The Rime of the Ancient Mariner"
by Samuel Taylor Coleridge

So far it is too obvious that we are literally surrounded by water, although salty (see Report – Water: The Big Picture). The most sensible thing to soothe the increasing thirst of human beings is therefore to desalt salt water, that is to say to remove salts and other dissolved solids and produce new freshwater.

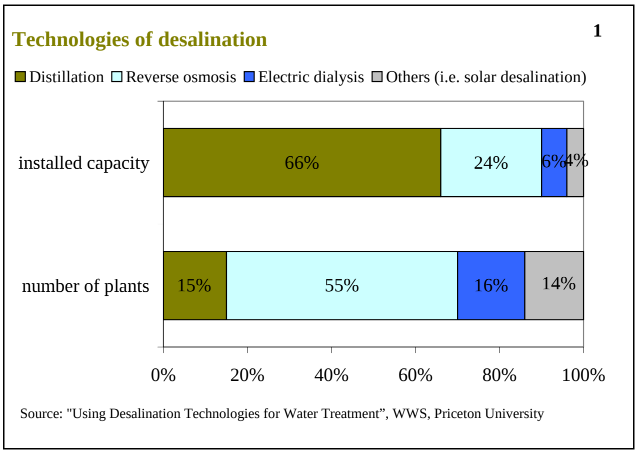
The advantages of desalination are various and of varied nature: availability is unlimited, access doesn't cause dispute or conflict at least for coastal states (unlike in the case of rivers shared by more than one country), construction of plants, unlike of dams, doesn't bring any forced migration of indigenous populations or dramatic changes of the environment. Last but not least technologies of desalination often allow scalability – that means a gradual implementation according to the dynamic of the demands -, quite the opposite to almost any kind of infrastructural projects of water supply.

SCENARIO

Today there are almost 12,500 desalination plants on the globe supplying 20 million m^3 of water per day, which is about 1% of the world production of drinking water. Increasing necessity of water and falling costs of desalination plants should bring the sector to grow in the next 10 years to almost $100 billion. Half of which, according to the estimate of "Research and Markets", generated by construction of new capacity of "production" - estimated 30 million m^3 per day - with capital expenditure of $30 billion and operational expenditure of about $18 billion.

Key to this growth will once again be the Arab Gulf region, where the combination of rapid increase in populations and substantial decrease of water reserves will create the need for doubling the total capacity of production of desalinated water.

Yet already today a great part of the global capacity is allocated in this area: Saudi Arabia which fulfils 70% of its water demand in this way, takes 30% of the world capacity of desalination, Kuwait and United Arab Emirates take 11% each. The US only comes 4th with 10%. But by now a great number of countries – although with smallest quotas – rely upon this technology to increase their water resources : as a matter of fact the 12,500 plants today globally at work spread over no less than 120 nations. Out of these plants, 15% are based on the so called **Multi Stage Flash** (MSF) technology - yet supplying two thirds of total capacity of **distillation** - 55% work with **reverse osmosis**, 16% with **electrodialysis** and the other 14% utilize other techniques. That practically means that distillation plants are much bigger (500,000 m^3 per day or above) than those based on the other technological approaches (see chart 1).



Source: "Using Desalination Technologies for Water Treatment", WWS, Priceton University

TECHNOLOGIES

Desalination is purifying salt water by removing dissolved mineral salts and other solids. A result that can be achieved by completely different physical and chemical principles: **Distillation**, **membrane filtration** and **dialysis**.

Distillation

The distillation process mimics the natural water cycle in that saline water is heated, producing water vapour that, in turn, is condensed to form fresh water. It is rather clear that the critical issue is production of the heat to allow to ignite the cycle of water evaporation. Therefore energy supply and efficiency of its use are critical. Because of that, distillation plants are often "in symbiosis" with thermal or electric power stations - which provide heat they have to disperse - to bring water up to the boiling point. The process of distillation has gradually sophisticated and evolved into the so called **Multi Stage Flash** (MSF), in which the heat of water vapour to condense into freshwater is recovered and used again to heat up water in the initial stage. This brings down energy consumption by a factor of 8 compared to the process without heat recycle system. And this has an impact on the costs: The initial costs of MSF plants amount

Advantages and disadvantages of desalination technologies 2

Method	Advantages	Disadvantages
Distillation	>The most renowned, so far obtained great reliance. >The best tolerance for low quality of original water	>The good functionality for a long period depends on quality of materials used in the construction phase of the facilities, that means it becomes quite >The facility of MSF is complex to install and difficult to operate.
Reverse Osmosis	>Simple facility for implementation and management >The existence of many suppliers promises a wide range of selection and competitive prices.	>Membranes are subject to rapid deterioration esp. if original water contains a lot of solids in suspension. >Need to expect pre-treatment phases for water to "feed" for reduce the degradation of membranes. >Need constant exchange of the pieces and man power cares.
Electric Dialysis	>Easy to use. >High energy efficiency (more products and less waste in ratio to the used >Modest cost even if it depends on characteristics of place of facility and the original water.	>Actually there is only one supplier of the facility (Ionics). >Not offers barrier to germs. >It can be applied only to the case of use of salty water not sea water. >Requires continuous use of electricity (but electricity may break down).

between $1,000 and $2,000 per m^3 a day and the output price varies according to the size of the plants from $1 to $4 per m^3 a day.

Reverse Osmosis
It is the most frequently used desalination technology among those with filtration through membranes (see Report –Membrane versus wastewater). The starting point is the physical principle called "osmosis". Two containers of solutions with different concentrations are separated with a semi-permeable membrane. Water at the lower concentration starts to move into the other part until (the) concentrations on both sides reach equilibrium. The pressure at which the flow ceases is called "osmosis pressure". If higher pressure than the osmosis pressure is applied with a pump or something, the flow can be reversed and the salt water moves back through the membrane, leaving the salts behind and turning into freshwater. Thus the name - "reverse osmosis"- to this process that separates water and dissolved salts. It is no need to boil or change forms of water. The required consumption of energy is the one needed by the pump creating the pressure differential. This makes things simpler – and costs lower – compared to distillation. The average costs of construction of the plants are about $1,000 - $1,5000 per m^3 a day and the production costs range from $1 to $3 per m^3 a day.

Electrodialysis
Salts dissolve in water mainly in the form of ions; either positive (cations) or negative (anions). Dialisys attract and separate cations and anions by the means of electrodes with opposite charge. Applying this principle to salt water, it is possible – through the generation of an ongoing electric field – to provoke the migration of ions beyond the selective membrane (cation-repulsive and anion-repulsive) producing water freed from the dissolved salts. Although it's use is advisable under specific circumstances (see **Advantages and Disadvantages** in chart 2), electrodialysis can be very interesting in terms of costs. The initial costs may vary from $500 to $1,000 per m^3 a day and the operation costs are in the range from $0.5 to $1.5 per m^3 a day.

RECENT INNOVATIONS

Energy consumption is (a) critical in the process of desalination. As a matter of fact it's the factor that - directly or indirectly (through its impact on the final costs of output) - often hinders this kind of solutions Therefore efforts of innovation are often focused on energy savings.

Two process innovations are interesting and actually prominent because both allow dramatic improvements of energy or economical yields of desalination.

The first one is called Rapid Spray Distillation (RSD). It is an alternative and more effective method to realize distillation. Invented by AquaSonics, Albuquerque, USA, RSD ejects the salt water through a nozzle into a stream of heated air while the conventional distillation boils salt water to obtain water vapour. Misty droplets of small micron in diameter in the heat of stream come to rapid evaporation. Then water vapours condense to form distilled water. At the same time dissolved salts "precipitate" in the solid form.

This method obviously simplifies both the process – that is carried out in a single stage – and the problem of the disposal of the supersaturated water or brine produced by the conventional process. That allows a decrease in costs. The construction costs of the plants are halved as there's no need for a boiler room. Operational costs decrease drastically due to greater efficiency and less impact from disposing materials.

The second "breakthrough" technology is one which is called "Long Beach Method". The name comes from the city of 500,000 inhabitants in the coast of the southern Los Angels where the first plant based on this method is located. According to Diem Vuong, General Manager of Long Beach Water Dept, who conceived this process variation, the new method assures a reduction of one third of energy consumption as compared to normal reverse osmosis, and this obviously affects the final costs of output. This is possible as the process in which the seawater is pushed against the membrane separation is divided into two paths. "Instead of pushing water to a single membrane with a pressure equivalent to 1000 psi", explains Vuong. "We use two membranes of nanofiltration". After a preliminary filtration step that eliminates the suspended materials the first osmosis path is run at 525 psi . Only molecules of smaller salts (about 12% of the total) pass through this step; a second path run at only 250 psi refines the purification. "The final energy consumption", concludes Vuong, "can be lower by as much as 30%.

TOP PLANTS

Among various desalination plants under construction or at work there are at least three worth to be mentioned because of their technical or economical characteristics.

- Apollo Beach in Tampa Bay, USA
It is the biggest in the US and realized in symbiosis with the adjacent Big Bend Power Station which

allows a deep cut in operative costs, thus also in the output price. The Power station in fact supplies “Tampa Bay Seawater Desalination facility” with “readily available” (filtered and heated) seawater and the energy to operate the plant of reverse osmosis. That permits to extract everyday from 44 million gallon of seawater which is “passed” from the Power Station more than 25 million gallon of freshwater at the final cost of $2 per thousand gallons, which is well below the standard price of the desalinated water, although it is still a double of the cost of groundwater. With a total construction cost of $110 million the plant is nowadays forced into a “stop and go” mode by the some technical-legal disputes, one of which is the major facility supplier’s bankruptcy.

- Ashkelon Desalination Plant, Israel
It was initiated in 2003 and its completion is expected by mid-2005. When finished it will be the biggest desalination plant (of desalination) in the world using reverse osmosis with a 110 million m^3 per year potential production at the cost of $0.5 per m^3. The project cost is $210 million and it is only the first of a series of similar plants that Israel plans to construct in the next years in the areas of Ashdod, Palmahim, Kishon and Cessarea.

- Perth Desalination Plant, Australia
It is under construction near Kwinana Power Station, 40 km south to Perth. When completed in 2006, it will be the biggest desalination plant in the Southern Hemisphere. The estimated cost is $240 million and will be able to produce up to 45 million m^3 per year, increasing by 20% the water resources in the city of Perth and adjacent zone.

Stefano Gulmanelli

Rainwater harvesting

A 4 million dollars plant that treats polluted stormwater and, once purified, discharges it into the Pacific Ocean. They're building it in Dana Point, California and it is named Salt Creek Ozone Disinfectant Facility. It deploys **ozonization** (see box 1) as technology for purification to reduce the bacterial levels of stormwater of the region and will treat up to 4 thousand litres per minute.

1

Ozone

Ozone (O3) is an isotope of oxygen and it is the most effective "anti-pollution" tool developed by Nature: it bonds its third atom of oxygen with the polluting substance, neutralizing it via oxidation and provoking its decomposition in water, carbon anhydride, sulphur, nitrogen and oxygen. This makes ozone the most powerful sanitary and antibiotic agent ever known.

Ozonization

Ozonization - that is administration of ozone into the substance to be treated - is a main option to purify and make water, also rain water, drinkable. To have an idea of the effectiveness of this process it's enough to remember that a level of ozone of 0.04 ppm (part per million) can kill bacteria, molds and fungus in just 4 minutes. For example, two parasites as dangerous as Giadia and Cryptosporidium are stopped through treatment with ozone but not with chlorine. Taking as a standard the time needed to kill 99.9% of all the micro organisms, ozone works out 25 times more effectively than hypochloridric acid and even 2,500 times more than hypochlorite. Furthermore, ozonization doesn't leave any trace – other than purification - on the treated water.

Purifying water to throw it into the ocean! It might seems foolish, at the least. Instead, it is the clear sign of a possible and above all probable evolution toward a scenario where provision of drinking water will increasingly depend also on the recycling of meteoric water. So far we've been worrying about meteoric waters only for their potential of contamination due to the typical "stormwater" pollutants: chemical compounds - such as calcium, magnesium, potassium, sodium, bicarbonate, chlorine, sulphate, nitrogen compounds, phosphate, cadmium, copper, iron, lead, nickel an zinc - all from various sources (see box 2).

Chemical constituents of atmospheric precipitations 2

Unlike conventional thinking, rain - that is the most common feed for the aquifers -, is nothing similar to distilled water. Rain water may actually contain chemical substances derived from:

- Eruptions from volcanos
- Emission from Earth's crust of gasses and sublimation of solids
- Dust and other solids brought in the atmosphere by the wind
- Marine spray
- Gas and other metabolic products introduced in the atmosphere by living organisms
- Reactions caused by thunders and cosmic rays
- Human pollution

Salt Creek Ozone Disinfectant Facility is just one of the plants, mostly in the US, under development for stormwater treatment. Some might be meant to preserve water areas for the purpose of recreation (swimming or fishing); others should avoid contamination of aquifers. But everyone of them is increasingly considered as a potential "source" for drinking water (and /or for agricultural purpose), at least in municipalities and regions where "natural" water is scarce.

It is obvious that the example of Dana Point is in many aspects an extreme one. Recovery and treatment of meteoric water often doesn't and will not rely on advanced technologies like those embedded in a $4 million plant. In most cases, the process takes the form of the implementation of management practices of rain water that allow both the progressive increase of the quota of usable meteoric water and the progressive extension of its use, to the extent of making it drinkable. A kind of "best management practices", that will end up fading the traditionally clear borderline between the simple control of runoff and capture of stormwater and the development of treatment techniques for its reuse.

A bright example in this direction is the increasingly diffusion of "intelligent" systems of rain waters recovery. Systems that perform an automatic separation of the meteoric water in "initial rain" (quite loaded with pollutants coming from the 'washed' surfaces) and "middle rain". The former is eliminated into the sewage system while the latter is conveyed (maybe after preliminary filtration) to feed water services that don't require drinking purity (for example, irrigation facilities, fire hydrants, rinse and sanitary use, industrial utilization).

Stefano Gulmanelli

Membrane versus wastewater

SCENARIO

It might look like the last option to embrace because of lack of alternatives, but that's not the case. Reuse of wastewater may as a matter of fact become in many situations the source of water provision not only because water has become increasingly scarce but also because treatment technologies have reached a level of effectiveness that the quality of such recovered water can be as competitive – both economically but also qualitatively - as the one drawn from the aquifers. The only exception may be the water to drink, but that's mainly due to psychological reasons. "Combination of diverse membrane filtrations" comments YuJung Chang, a PhD in "Water Treatment" and Vice President of HDR, one of the major consulting firms in management and treatment of water, "can bring reclaimed water up to such a high-quality water that it can be used for drinking purposes."

It's highly probable that the threshold in making wastewater drinkable will be crossed only if there's no other choice, but we can take it for granted that in the near future the great urban aggregations, both in advanced and developing areas, will proceed along the path to recover wastewaters for all non drinkable uses, such as irrigation, car wash, toilet flushing and provision for fire hydrant. "Indeed," added Chang, "the overall wastewater treatment market in the US is estimated to increase from $522 million in 2000 to $756 million by 2007 and the biggest part of this growth is in equipments for wastewater reuse".

A CHAIN OF ADVANTAGES

Furthermore, reuse of reclaimed water leads to a number of advantages, although often indirect. For example, conveying - after a preliminary rough treatment - sewage waters to agricultural initiatives, supplies crops with additional nutritive ingredients, at the same time avoiding contaminations of water streams which far too often end up being the receptor of wastes. An immediate consequence is that the need for new infrastructures for sewage disposal is reduced or delayed, as are the problems and consequent interventions related to the discharge of wastewater in rivers, lakes and the sea. Another effect is that we can release stress on water reservoirs for irrigation related needs; and those same reservoirs can themselves be provisioned with treated recycled water. This, as a final consequence, diminishes the need for "importing" water from other reservoirs - often located hundreds of miles away – saving energy as well. Thus, it is not by chance, that plenty of significant experiences of reuse of "wastewater" are found in all the five continents and in various fields; agricultural use, urban usage, industrial use, or reintegration of existing hydro resources. (see boxes 1-4)

Cases of reuse in agriculture 1

- **Monterey, California**. Every year approximately 20 million m^3 of water discharged by the city of Monterey and the adjacent area are used to irrigate 5,000 hectares of agricultural cultivation in the Lower Salinas Valley.
- **Mexico City**. Almost 90% of the wastewaters of the Mexican capital is re-utilized to irrigate the Mezquital Valley. Due to this the yield of harvest has significantly increased.
- **The Dan region, Israel**. Israel is by far the country with the most advanced system of wastewater recycle. As a matter of fact 70% of the country's sewage water is re-utilized in agriculture and by 2010 almost 20% of the country's water supply will come from the recovery of recycled water. It is thanks to 130 million m^3 per year of treated wastewater discharged by Tel Aviv that the agricultural miracle of the Dan region and Negev desert is possible
- **Virginia, Australia**. In southern Australia, the sewage water treatment plant of Bolivar supplies yearly 30 million m^3 with water the agricultural area of Virginia, north of Adelaide.

Cases of reuse in urban area 2

- **South Bay, California**. The South Bay Water Recycling Scheme daily supplies users in Silicon Valley with more than 60,000 m^3 of reclaimed water - a quantity to be doubled in 2005. The San Jose-Santa Clara treatment plant used to discharge into the Bay area the fresh water coming from the treatment plant, altering the environmental conditions and threatening the eco-system. Instead of spending money to provide the plant with an ocean waste, the decision was to launch a scheme to re-utilize the treated water for urban use.
- **Homebush Bay, Australia**. The former Homebush Bay Olympic Area in Sydney is daily supplied with 7,000 m^3 of reclaimed and treated wastewater to flush toilets and irrigate the communal spaces both in sports facilities and in residential zones. The recycled water relieves Sydney's water demand by about one million m^3 per year.

Cases of reuse in industry 3

- **Singapore**. The Singapore NEWater project provides treated recycled water to a sophisticated activity – which requires above-standard pure water - such as the production of semi-conductors. Nowadays Singapore is supplied with more than 100,000 m^3 of purified water, an increasing amount of which is conveyed to supplement the reservoirs for drinking water.
- **Port Kembla, Australia.** Bluescope Steel is located south of Sydney and it's by far the greatest user of the water reservoirs in the Wollongong area. Using recycled water (50,000 m^3 per day) has more than halved that consumption.
- **Phoenix, Arizona**. The Power Station of Palo Verde, located in the Sonora desert, where rainfalls rarely reaches 200 mm per year, uses 250,000 m^3 of water recycled from Phoenix (55 km westward) to cool its turbines.

Cases of reintegration of the existing water resources 4

- **Upper Occoquan, Virginia**. From 10% to 15% of the water stored in the Upper Occoquan's great reservoir, which provides potable water to almost one million people in northern Virginia, is wastewater that has been reclaimed and treated. The treatment plant pours almost 200,000 m^3 per day into the reservoir.
- **South Africa**. The Hartbeespoort Dam is a giant dam that provide water to the highly populated areas of Pretoria and Johannesburg; Half of it is filled with recycled water.
- **Windhoek, Namibia**. Squeezed between the Kalahari desert and the Namib desert and located 750 km apart from the nearest semi-perennial river, since the Seventies Namibia's capital Windhoek couldn't help depending on reuse of returned water to soothe its own population's thirst. Thanks to membrane technology, today the wastewater treatment plant daily supplies more than 20,000 m^3 to the reservoirs of drinking water.

TECHNOLOGIES OF RECOVERY

Pollution, men's use, contamination due to production activities, natural accumulation of toxic compounds and other more or less natural causes produce increasing amount of "wastewater" – that is water which is no longer usable. To reverse the result and make such water re-usable can be done via two technological approaches:

Biological elimination of contaminants (Bioremediation)
Physical removal of particles and pathogens

Both have pros and cons. The choice among the two techniques mainly depends on the original condition of wastewater, the requested level of quality and – which is consequent - the desired use for the recovered water. All this within a framework of social considerations and economic restrains. At the end of the day, as it always happens, also in this case choosing the tool is related to the aim on one side and to the "environmental" constraints on the other.

Bioremediation

Basically, it's annihilation of contaminants via biological means. It's the process with which micro organisms in a controlled environment degrade organic contaminants and remove inorganic contaminants. The biological transformation thus generates less toxic or even innocuous products, reducing the concentrations of pollutants to levels consistent with the relevant regulations.

The most used technique of bioremediation is the "aerobic" one, where aerobic micro organisms use pollutants as a source of energy for their reproduction, that can be carried on only if a sufficient quantity of oxygen is present. As a consequence, the available techniques of bioremediation (bioventing bioslurping, biosparging) are basically nothing else than methods of oxygen administration. The by-product of the transformation of pollutants into microbial biomass is often constituted solely of anhydride carbon and water. Anaerobic bioremediation – in which the biodegradation occurs thanks to nitrates instead of oxygen - has been experimented in particular conditions, but results are far less satisfactory.

Physical removal of contaminations

The process is to physically separate water from the polluted elements that turned it into "wastewater". Technically speaking, this separation can be pursued through two fundamental approaches:

-Technologies which are not based on use of membrane (non-membrane technologies)
-Technologies which use membrane (membrane technologies)

Non-membrane technologies (see box 5) have a number of restrictions so that - in terms of performance, energy efficiency, cost and other reasons - they result being quite less satisfactory for water recovery and anyway they lose vis a vis "membrane technologies". This is why it's often said that membranes are the real frontier in wastewater recovery, as Dr. Chang points out: "Membrane constitutes the most reliable technology to remove pathogens and soluble inorganic particles. In other words, this type of treatment can eliminate any kind of contaminants of water."

Non-membrane technologies 5

Conventional methods without filtering
- Distillation – Molecular separation via the heating of the original liquid and the condensing of the generated water vapour
- Electrodialysis – Extraction of ions from water
- Pervaporation – Extraction of molecular gas and volatile solutes
- Gas Transfer - Transfers of molecular gas from (or inside of) the water

Filtering (conventional techniques)
- Screen filtering – It holds back waste materials beyond the holes (with different sizes and shape) of the filter
- Filtering by coagulation – It chemically coagulates the undesired particles to make it possible to filter them out
- Filter by clarification – It eliminates (by the means, for example, of sands) turbidity of water

The basic concept of "membrane technology" is quite simple. A pressure differential is created between two different containers - one being at the starting point, the other at the destination – separated by a membrane, whose permeability let the water flow from one container to the other holding back impurities. Thus what migrates beyond the membrane is only water which is refined from undesired compositions.
In the field of membrane technologies research and development and hereby derived innovations have been - and will be – focusing on the different aspects (see box 6) ; it's because of the evolutions in the last 15 years, that today membrane filtration technologies can assure the elimination of any type of contaminants from water of the most diverse sources.

Research areas of membrane sectors 6

- Search for better membrane material
- Search for ways to modify membrane characteristics

- Redesign the membrane module configuration to maximize the production, and minimize the cost
- Re-engineer the production line to improve Quality Assurance and Quality Control
- Search for better ways for membrane cleaning

Source:HDR

At the end of the day, the real issue is being able to choose a specific type of membrane according to the desired goal. "There are two main types of filtering by the means of a membrane", explains Chang, "the first one is the so-called 'low-pressure membrane', which has relatively wide pores and operates with pressure differentials which are minimal. In this category we have micro-filtration membranes, which are used to remove turbidity or bacteria, and ultra-filtration membranes, through which the removal of viruses can be achieved. The water coming out of this treatment is free of particulates and can be considered 'pathogen free' but still contains traces of sodium, nitrates, phosphates and various other soluble organic substances; this restricts its use to non-potable utilization. To achieve greater purity 'high-pressure membranes' are needed:

this is the realm of nanofiltration or, even better, reverse osmosis that can give output of water of quality that one can drink". (Type of membrane technology –see box 7)

Type of membrane technology 7

Type of process	Operation method
Micro-filtration	Removal of suspended solids, micro organisms included
Ultra-filtration	Removal of big soluble molecules and suspended colloid particles
Nano-filtration	Removal of multivalent ions and polar molecules
Reverse Osmosis	Removal of inorganic ions and of all the soluble solids

Membrane technologies are increasingly efficient, the facilities that use these approaches are –given the same amount of treated water – much smaller compared to those with competing technologies and their cost have been decreasing in the last ten years. These are elements that put membrane technologies at the centre of the stage for the future of wastewater treatment. But there's more: "In case of terrorist attacks on drinking water reservoir or with the appearance of unknown pathogens, membranes are definitely a superior option" Dr. Chang underlines. It is true that membrane technologies are expensive and require a certain level of operational skills as compared with traditional methods of purification: "I would not recommend membranes to produce drinking water in low-income economies and less technically developed societies unless project is externally funded and the treatment plant is operated by properly-trained technicians" says Dr. Chang, "And the same applies to wastewater recycle: the cost is relatively expensive due to the quality of the original water. Therefore wastewater membrane applications are usually adopted by well-established economies that strategically decide to use membranes to produce supplemental water supply".

Nevertheless, it's highly probable that purification via membranes will progressively become affordable for an increasing number of countries and economies thanks to the steady decrease in cost. This is a trend that could be stimulated by competition (Dow, Hydranautics, Koch Membrane Systems, Ionics, Zenon Environmental, USFilter, Pall and Norit are main players on a fairy crowded market) and by a quite high innovation rate. Speaking of innovation, two latest developments in membrane materials may have extraordinary impacts on performance and cost.

Liquid membranes, which are membrane composed of liquids. In their simplest shape, liquid membranes – highly effective and selective – are membranes with micro pores in the rigid structure of separation which are filled with a liquid (so called 'carrier') that works as a filter and holds back contaminants.

Membrane of carbon nanotube. Invented 15 years ago by Sumio Iijima, a researcher at NEC, carbon nanotube, although 50 thousand times thinner than a hair - is the most resistant fibre created, ever. It's thousands times more resistant than silver and copper, six times lighter than steel. On top of that, it can resist very high temperatures. Researchers of Rensselaer Polytechnic Institute of Troy, NY and Banaras Hindu University, Varanasi in India have recently created a membrane filter based on carbon nanotube. After they forced contaminated water through it, the membrane showed being able to hold back not only Escherichia coli, the bacteria responsible for intestinal infections, but also poliovirus, whose size is in the magnitude of 25 nanometers.

The extension of the surface area of carbon nanotube membranes, their relatively cheap production cost and the fact that they can be easily cleaned (by means of high temperature or ultrasounds that the structure can stand) draw a perspective scenario in which these type of membranes will most probably become extremely competitive in respect of ceramic or polymer based traditional membranes.

Stefano Gulmanelli

Water's weird characteristics

Transparent, colourless, odourless. Present anywhere. Chemically composed by the most diffused elements in the Universe. It would be easy to jump to the conclusion that water is an ordinary substance. Instead, water conceals quite a few properties and characteristics which are chemically and physically unique and that no other liquids have. These are those same characteristics that make water the central element of life and the basic component of living organisms- we should never forget that from 60 to 90% of cells and tissues is made up of water.

Above all, water is the only substance which at environmental temperature and pressure is found in all three physical forms; solid (ice), liquid and gas (damp). This is the main reason for its vast diffusion in nature.

Secondly, water has a "specific heat" which is so high that it absorbs more heat than any other compound. That makes it useful to cool down the environment by seizing heat, and vice versa maintaining heat since water stores it and releases it slowly. A feature that explains the fact that in winter coastal zones - compared to inland - enjoy mild temperature, mitigated by the heat accumulated in lakes and the sea in summer and released in cold seasons.

No less important is the polarity of the water molecule: a positive charge at one extreme and a negative charge at the other (an effect given by the bond among the two atoms of hydrogen and the atom of oxygen composing the water molecule - a bond which is not linear, having an angle of 105 degrees). Because of the "electric bipolarity", water is an excellent solvent. Or, better, the best liquid solvent. This is a decisive feature for living organisms, since it allows the complex chemical reactions which are fundamental to life itself (just think to those happening in the blood or into cellular cytoplasm).

Last but not least, the most curious among the visible features of water: the fact that – contrary to the greatest part of liquids - when it turns to solid, it increases volume and loses density. The result is the buoyancy of ice, a phenomenon of decisive importance for the life of the organisms living in water. As a matter of fact, the ice layer formed during winter on the surfaces of rivers, lakes and the sea basically acts as a thermal insulator: it prevents the lower layers from solidifying, and therefore keeps life going in the depths. Should ice not float, it would pile from the depths up to the surface, freezing the whole mass of water and trapping all living entities inhabiting it.

Arianna Dagnino

Search for water somewhere else

Every rocket that human beings launch for space exploration somehow searches for water. It is because traces of water are regarded as the minimum requirement for the existence of possible form of life, if we rely on the assumption – never contradicted on Earth - that "life is born from water".

Water consists of two elements, hydrogen and oxygen. The origins of these two elements are respectively the Big Bang and the stellar nuclear fusion. This leads us to assume that the presence of water can be rather diffused in the Universe (the so called "cosmic water) although not in the liquid form as we are accustomed to on Earth. As a matter of fact it is only our planet that happens to meet the right combination of temperature and pressure for water to stay liquid.

There have been relatively few missions through which it has been possible to carry on the chemical analysis of the surfaces and atmospheres of the planets in our solar system or the spectroscopic analysis on the celestial bodies, but they were enough to identify a number of possible "reservoirs" of cosmic water in the form of water ice.

It's the case of the Moon, whose craters near the poles reflects the radar signals emitted by orbital rockets around our satellite in a way that makes us presume the presence of a great quantity of ice under its crust. It's the case of Mars; its atmospheric pressure (100 times less than that of Earth) doesn't allow water to exist in the liquid form, but its polar caps – although mainly composed of carbon anhydride - increase in winter and decrease in summer, a strong evidence for traces of ice water.

And it's the case of Europe, a moon of Jupiter, with its surface scratched with fractures, probably caused by ice keeping freezing and melting continuously, that gives way to speculation on the existence of a liquid ocean under the frozen crust.

Yet planets are not the only ones in the list of the possible reservoirs. In that list we certainly can find comets, mixed aggregations of water ice, stones, rocks and other frozen compounds like methane and ammonia. "Dirty snow balls" – as they often are referred to - that some scientists believe to be the source of the water which filled the oceans on Earth during their formation. Another possible reservoirs are the "interstellar clouds" and their dust, in which the spectrum of light generated by a molecule of water has been repeatedly recorded.

All or some of these – and others similar - might one day, in a far future but fascinating future, become sources for human beings to calm our inexhaustible thirst. Thirst of water but, at the same time, also of knowledge.

Arianna Dagnino