

FRESH WATER AUGMENTATION

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“Water, water, every where,
And all the boards did shrink;
Water, water, every where,
Nor any drop to drink.”

“The silly buckets on the deck,
That had so long remained,
I dreamt that they were filled with dew;
And when I awoke, it rained.”

“My lips were wet, my throat was cold,
My garments all were dank;
Sure I had drunken in my dreams,
And still my body drank.”

“He prayeth best, who loveth best,
All things both great and small;
For the dear God who loveth us,
He made and loveth all.”

“The Rime of the Ancient Mariner,” Samuel Taylor Coleridge, 1863.

INTRODUCTION

Water is becoming to the 21st century what petroleum was to the 20th century: the most precious commodity that determines the wealth of nations. There is no shortage of energy, but a looming shortage of water exists for large parts of Australia, Asia, Africa and North America. Since the 1940s, the world population has tripled to more than 7 billion, whereas water use has quadrupled. By 2020, 37 percent of the global population is expected to face severe water stress, even though 16×10^6 tonnes of water of rain falls per second around the world. From 0.78 to 1 billion people on Earth are without reliable and basic water supplies and about 2 billion lack the requirements for water sanitation. By 2025 the United Nations (UN) expects that 14 percent of the world's population will face water scarcity. As the effects of climate change continue to reduce urban water supplies, wealthy modern countries are investing in desalination technologies.

The Claude "Bud" Lewis Carlsbad Desalination Plant is a 50 million gallon per day, or 56,000 acre.feet per year (AFY), seawater desalination plant adjacent to the Encina Power Station in Carlsbad, California. Desalination has evolved into a desirable water supply alternative by tapping the largest water reservoir in the world; the Pacific Ocean. The technology, available for decades, is at work in many arid areas of the world including the Middle East, the Mediterranean and the Caribbean. The plant has been delivering water to the businesses and residents of San Diego County since December 2015. San Diego County is home to an international desalination industry, with over 35 desalination-related companies employing 2,200 people and generating over \$200 million in annual revenue.

There are over 21,000 desalination plants worldwide, producing over 3.5 billion gallons of potable water a day. Overall, desalination plant capacity has increased exponentially over the past 30 years. Saudi Arabia leads the world in desalination and relies on it to meet 70 percent of the country's drinking water needs.

The Reverse Osmosis (RO) desalination plant fresh water's cost is \$1,300–\$1,400 per acre-foot, which is about 4.5 times the cost of local reservoir water at \$300 per acre-foot. It is slightly comparable to recycled municipal water at \$1,200 per acre-foot, and cheaper than imported water at \$1,500 per acre foot. An acre-foot is the fresh water usage of two families of four per year. If technology can bring the desalinated water cost to the \$300 per acre.ft level, coastal California can depend on desalination plants and would not need to build any new reservoirs, pipelines, or canals.

According to the USA Environmental Protection Agency (EPA), 92 percent of our blood, 75 percent of our brains and muscle, 60 percent of our bodies and 22 percent of our bones are composed of water. Humans can live a month or so without food, but cannot survive for more than a week without water.

According to Ismaïl Serageldin, World Bank's environmental expert: "The wars of the twenty-first century will be fought over water. The demand for fresh water continues to increase at an unsustainable rate under the pressures of population growth and industrial expansion. On the other hand, the world's supply is being depleted by pollution, the draining of fossil underground water aquifers and climate change affecting the 6.8 billion humans in 2010 increasing to 9 billion by 2050, and other species that co-inhabit planet Earth. By 2008, the global consumption of water had a doubling time of 20 years; more than double the population growth rate.

Water is considered as an "axis resource" that underlies all others such as energy and food production. Desalination plants need 3-5 years to be built, cost a large amount of capital and require large amounts of energy for operation. Currently about 1.2 billion people lack safe drinking water, to increase to 3.4 billion by 2025. Third World inhabitants obtain their water from rivers, streams, lakes and ponds that are riddled with disease organisms. Even groundwater from wells could be tainted. A child dies every 20 seconds from water-related disease: Typhoid, Cholera, Arsenic poisoning, enteric and diarrheal bacterial and viral diseases, and the cysts of 30 species of water-borne parasites.

The United Nations' water agency (UN Water), estimates that water use has been growing at more than twice the rate of population growth in the last century due to demands such as irrigated agriculture and meat production. More than 40 percent of the world's population already live in conditions of water scarcity. By 2030, UN Water estimates that 47 percent of the world's population will exist under high water stress.

The Earth is a water planet with 326×10^{18} gallons of water or 1.26×10^{21} liters. The Earth's surface is 70 percent covered with the oceans. Only 2.5 percent of water on Earth is fresh water, the remaining 97.5 percent is brackish or saline water. The fresh water supply is apportioned as 0.4 percent in lakes and rivers, 30.9 percent as groundwater, and 68.7 percent as snow and ice.

The world irrigated agricultural area reached its peak in 1980 at 75.5 hectares (ha) / 1,000 people in 1980. By 2010, it has fallen to 43 ha / 1,000 people; at the same level as 1960. A hectare is 2.47 acres, and an acre is 4,840 square yards. (1 feddan = 24 kirat = 60 meter \times 70 meter = 4,200 m² = 0.42 hectares = 1.038 acres).

In manufacturing, it is estimated that the production of a single USA automobile uses about 39,000 gallons of water. Water is essential in the production of energy: A typical 500 MWe power plant uses about 2.2 billion gallons / year to produce steam to run its turbines and for cooling

purposes. This is enough fresh water to support a city of 250,000 people. Over 21,000 desalination plants exist over the world producing 3.5 billion gallons of potable water per day.

Water is essential for food production and agriculture which accounts for $\frac{3}{4}$ of all water drawn from rivers, lakes and aquifers. A new trend is emerging in the production of “pulses” or crops that are harvested for the dry seed such as lentils, chickpeas, peas and beans as sources of vegetable protein instead of animal protein. By weight, they provide as much protein as poultry and more than beef. However, it takes just 40 gallons of water to produce a pound of pulses compared with 2,000 gallons / lb of beef meat.

About $4,000 \text{ m}^3 / (\text{person}\cdot\text{year})$ of fresh water was available in the middle of the 20th century. Presently, this number is reduced to the water scarcity level of $1,000 \text{ m}^3 / (\text{person}\cdot\text{year})$. Around the world, 16 million tons of rainfall occurs every second. Yet only 0.3 percent of the world's total fresh water in ground water, rivers and fresh water lakes is potable and usable by humans. Just as the planet is reaching peak oil production, it appears to be reaching a similar peak fresh water supply, particularly in its arid regions. For instance, the High Plains Ogallala Aquifer in the USA with an average depth of 200 feet is the world's fastest disappearing fresh water source at 150 feet in about 20 years, and the water table under the Klamath Basin in Northern California is dropping at a rate of 6.7 feet per year. Droughts are intermittently suffered in China, Australia, Africa, and the Ukraine, leading to crop failures, dwindling grain stocks and rising food prices. In the 1950s China had 50,000 rivers with catchment areas of 100 square kms or more. The number is down to 23,000. This means that China has lost 27,000 rivers, mostly as a result of over-exploitation by farms or factories. Negotiations started between Russia and China for Russia to start selling fresh water, of which they have the largest proportion of the world's supply, to western China, delivered by pipeline.

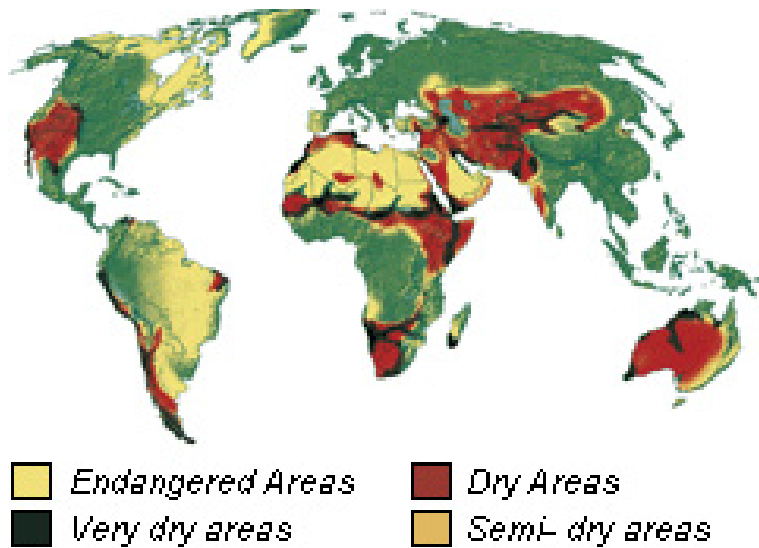


Figure 1. Arid regions of the World. Source: Enercon.

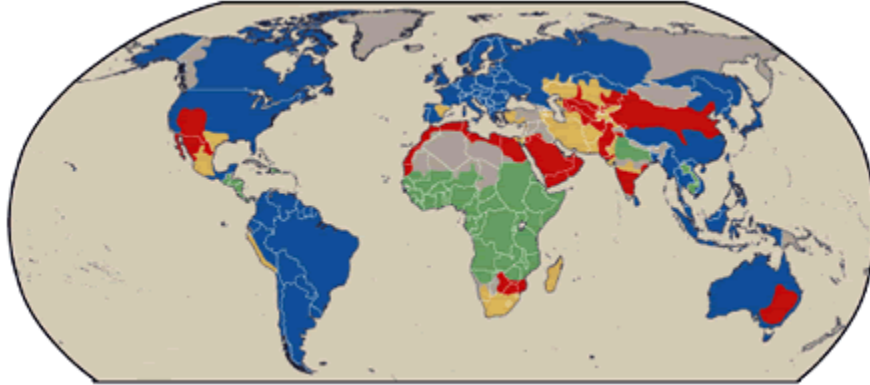


Figure 2. Expected areas of scarcity (red) by 2025. Source: International Water Management Institute.

The Scripps Institution of Oceanography at the University of California at San Diego reported that Lake Mead behind the Hoover Dam in Nevada, the USA's largest fresh water reservoir, and Lake Powell are at 50 percent of capacity and headed to zero capacity within 13 years. A drought in the state of Georgia threatened the water supply for millions of people, and Florida does not have enough water for its population growth. The Great lakes of North America are shrinking in size. Upstate New York reservoirs have dropped to record lows. The Sierra Nevada snowpack is melting faster by the year. The lack of sources for fresh water is a problem facing much of the American West, though the problem is particularly acute there and in the state of Nevada; the most arid state in the USA.

In 2014, a drought affected the state of California in the USA resulting in 800,000 acres of farmland left fallow. In 2013, this was 500,000 acres. Farm-related unemployment topped 40 percent in California's Central Valley. A drought in 2012 in the USA's Midwest sent USA corn prices soaring to above \$8 per bushel from \$2 per bushel.

The USA Environmental Protection Agency, EPA projects that an investment of \$335 billion is needed in pumps, piping, treatment facilities and other infrastructure by 2019. The state of Illinois alone would need a \$15 billion investment. About 80 percent of the 320 billion gallons per day (gpd) water use in the USA is used by agriculture. USA households use 29 billion gpd; around one tenth of the amount.

The tight water supply has implications all over the American West. For instance, in Arizona, one cannot build a residential development unless he finds a "designated assured water supply" that can sustain that development for 100 years. Population growth, environmental changes and pollution have placed fresh water supplies under severe stress.



Figure 3. Low level of stored water at Lake Mead behind the Hoover Dam due to reduced snow pack in the Sierra Nevada Mountains, February 2009.

In the Middle East, the water supplies are under extreme constraints. Ninety percent of the fresh water in Saudi Arabia comes from fossil sources and is running out. Water production has reached its peak around 1998.

Eighty percent of China's fresh water supply has been polluted by rapid urban and industrial growth. About 2.4 billion people worldwide lack water sanitation, causing the death of 4,500 children per day.

Water, as the most common solvent in nature, covers 70 percent of the water planet Earth's surface. It is thought to have originated from comets impacts and volcanic activity in its early history. It is essential for life on Earth. However, most of it nowadays is salty. As fresh water, it is an essential and critical ingredient in biological life including plant, animal and human existence. As the world's population grows, demand on the world's supply of fresh water follows. Fresh water is in short supply in most parts of the world, even more than electrical energy. The shortage affects 400 million people all over the globe, with this number expected to swell to 4 billion by 2050. To wrestle fresh water from salty and brackish water, energy at a cost and in some form or the other must be used.

About 1.5 billion of the world's 6.1 billion or 1/3 of the world's population that lives in areas where water is scarce, such as North Africa, Northern China, India or parts of the southwestern USA such as Arizona and Nevada, are expected to experience a severe water shortage by 2025. Another billion lives in regions where water was available in rivers and aquifers but where people lacked an adequate infrastructure to exploit it, such as in large tracts of sub Saharan Africa or northern India. One in three people in the world is enduring one form or another of water scarcity.

Conquering hunger and coping with an estimated 3 billion extra people by 2050 will result in an 80 percent increase in water usage for agriculture on rain-fed and irrigated lands. The demand for irrigation absorbs about 74 percent of all water used by people against 18 percent used for hydropower and other industrial uses and just 8 percent for households, and is likely to surge by 2050.

A single calorie of food takes roughly 1 liter or 0.22 Imperial gallon of water to produce. One kilogram of grain needs 500-4,000 liters, while 1 kilogram of industrially produced meat

requires 10,000 liters. Beef meat production accounts for 1.3 percent of the calories consumed by humans. Cattle occupy 60 percent of the available agricultural acreage, requiring 31.5 kW.hrs of energy and 2,500 gallons of water to produce one pound of meat.

Many nations are shifting to produce biofuels such as ethanol, butanol and biodiesel from sugar cane, beets, corn, palm oil, rape seed or canola or soybean oil or cellulosic matter as an alternative to fossil fuels. Increasing oil prices and worries about global warming are driving the shift. If biofuels and food will be grown, this will place another new stress on water usage. For instance the production of 1 gallon of corn ethanol needs the usage of 6-10 gallons of fresh water in the process.

The price of water depends on its cost of pumping then piping and conveyance using pipelines from its production site to its consumption site. An accepted figure is \$800-1,400 per acre.foot. An acre.foot of water is the amount of water required to flood a plain of 1 acre to a depth of 1 foot. One acre.foot of water can support two families of four for one year.

The average price of water in the USA, according to the NUS Consulting Group, has been increasing; and it climbed by 3.5 percent in 2005. It varies from \$5.49/1000 gallons (MGal) in Huntington, West Virginia, to \$0.80/MGal in Greenville, Mississippi. Its average cost was \$2.34/MGal in the USA. If the related sewer costs were included, the national average rises by 5.3 percent to \$5.78/MGal in 2005.

WATER SCARCITY

The International Water Management Institute defines water scarcity as shown in Table 1. The definition of water scarcity to water demand is conservative in that it implies that dry areas are not necessarily water scarce.

Table 1. Water scarcity categories. Source: International Water management Institute.

Category	Description
Physical water scarcity	More than 75 percent of river flows are allocated to agriculture, industries or domestic purposes.
Approaching Physical water scarcity	More than 60 percent of river flows allocation. Such water basins are expected to experience physical water scarcity in the near future.
Economic water scarcity	Water resources abundant relative to water use, with less than 25 percent of water from rivers withdrawn for human use, yet malnutrition exists.
Little or no water scarcity	Abundant water resources relative to use. Less than 25 percent of water from rivers withdrawn for human use.

FRESH WATER REPLENISHABLE AND FOSSIL AQUIFERS

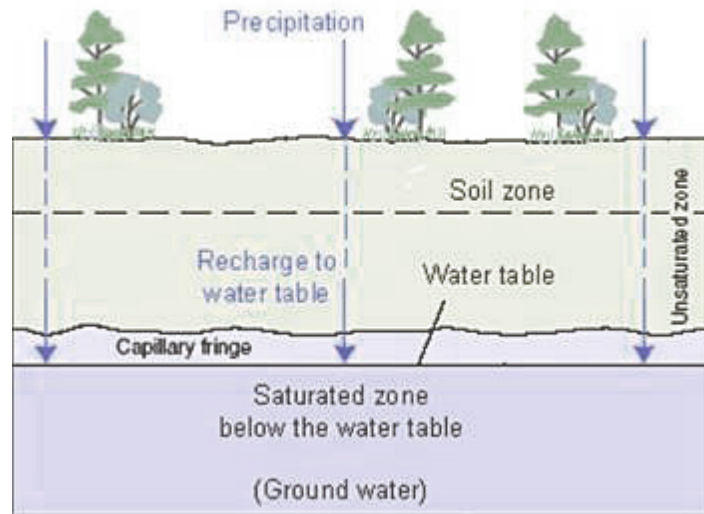


Figure 4. Aquifers occurrence. Source: USGS.

Freshwater aquifers are an important fresh water resource. Recently, the rate at which they are exploited has more than doubled from 126 to 283 km³ / year in the last few decades. If water were pumped at that rate from the USA's Great Lakes, that would dry them within 80 years.

The underground aquifers sustain streams, wetlands, and ecosystems and they resist land subsidence and salt water intrusion into surface fresh water supplies. In aquifers, the fresh water is held in the pores of the medium. Water infiltrates into the soil through the pores and cracks until it reaches the saturation zone, which occurs because water infiltrating the soil reaches an impermeable layer of rocks it cannot soak through. The water table is located at the top of the saturation zone.

Large metropolitan areas cities in the world such as Jakarta, Indonesia, Dhaka, India, Lima, Peru and Mexico City, Mexico depend on their underlying aquifers for their fresh water supplies.

Aquifers can be replenishable with a permeable layer of rock above the water table and an impermeable one beneath it, and non-replenishable or fossil no-recharge aquifers. The aquifers in India and the shallow aquifer under the North China plain are replenishable. When these become depleted, the maximum rate of pumping is reduced to the rate of recharge or refilling.

In the case of the fossil aquifers, such as the USA Ogallala aquifer, the deep aquifer under the North China Plain, or the Saudi Arabia aquifer, depletion would bring pumping to an end. The highest rates of groundwater depletion occur in the world's major agricultural centers of Northwest India, Northeastern China, Northeast Pakistan, California's Central Valley, and the Midwestern USA.

About 87 percent of the irrigated corn in the USA is grown in regions of high water stress. According to the Ceres organization, over ½ of the irrigated corn production depends on ground water from the over-exploited High Plains water aquifer. In addition, 36 corn ethanol refineries are located in, and source corn that is grown in this aquifer, an unsustainable situation. Yet, 16 sectors of the USA economy depends on corn as an ingredient.

China's wheat crop is grown in the semi-arid northern part of the country and is particularly vulnerable to droughts. A World Bank study suggests that China is over pumping three river basins in the north, the Hai River, the Yellow River and the Huai River. The irrigated land accounts for 4/5 of the grain harvest in China.

In India, 21 million drilled wells are lowering water tables in most of the country. In North Gujarat, the water table is falling at a rate of 6 meters / year. In the state of Tamil Nadu the falling water tables have dried up 95 percent of the wells owned by farmers. The irrigated land accounts close to 3/5 of the grain harvest in India. Indian water well drillers, using modified oil drilling technology are drilling at 1,000 meters in depth. India is the largest user of groundwater resources in the world using an estimated 230 km³ / year. That figure is more than 1/4 of the total world consumption from this resource. In the Pakistani part of the fertile Punjab plain, the drop in the water table appears to be similar to that in India.

In the Northern USA, the water levels in the Ogallala aquifer under the Great Plains, considered as the world's bread basket and providing about 30 percent of the USA irrigation groundwater, are precipitously declining. The Ogallala Aquifer is the world's largest fresh water aquifer with an area of 450,600 km² and stretches from southern South Dakota through Nebraska, Wyoming, Colorado, Kansas, Oklahoma, New Mexico, and northern Texas. It was formed 10 million years ago when water flowed into the Great Plains from the retreating glaciers and streams of the Rocky Mountains.

The Ogallala Aquifer is fossil water and is no longer being recharged by the Rockies snow melt, and precipitation in the region is just 30-60 cm per year. In the three leading grain producing states of Texas, Oklahoma, and Kansas, the underground water table has dropped by more than 30 meters. In Kansas, when the wells were put down into the Ogallala aquifer in the 1940s, they went 30 foot down into a 180-foot-deep aquifer. Those wells were pumping 1,500-2,000 gallons per minute in the 1950s. As of 2012 the aquifer is 135 feet in depth, and they are pumping 200-250 gallons per minute to preserve the water supply.

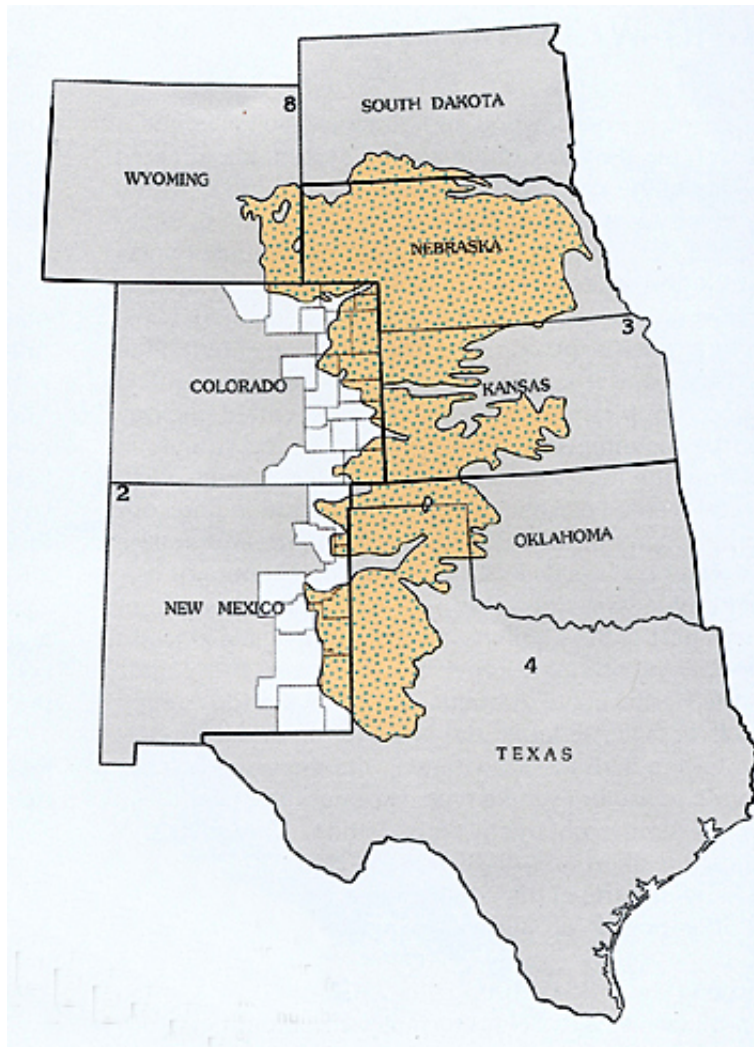


Figure 5. USA High Plains Ogallala Aquifer covers about 174,000 square miles in eight states. Source: USGS.

Era	System	Series	Stratigraphic unit		Hydrogeologic unit	Physical characteristics
Cenozoic	Quaternary		Holocene and Pleistocene		High Plains aquifer	Gravel, sand, silt, and clay
	Tertiary	Upper	Miocene	Ogallala Formation		Unconsolidated, poorly sorted gravel, sand, silt, and clay
				Arikaree Formation		
	Lower	Oligocene	Brule Formation	White River Group		Siltstone with sandstone as beds and channel deposits
			Chadron Formation			Clay and silt
					Contining unit	

Figure 6. Geological age and composition of the USA's High Plains (Ogallala) Aquifer. Source: USGS.

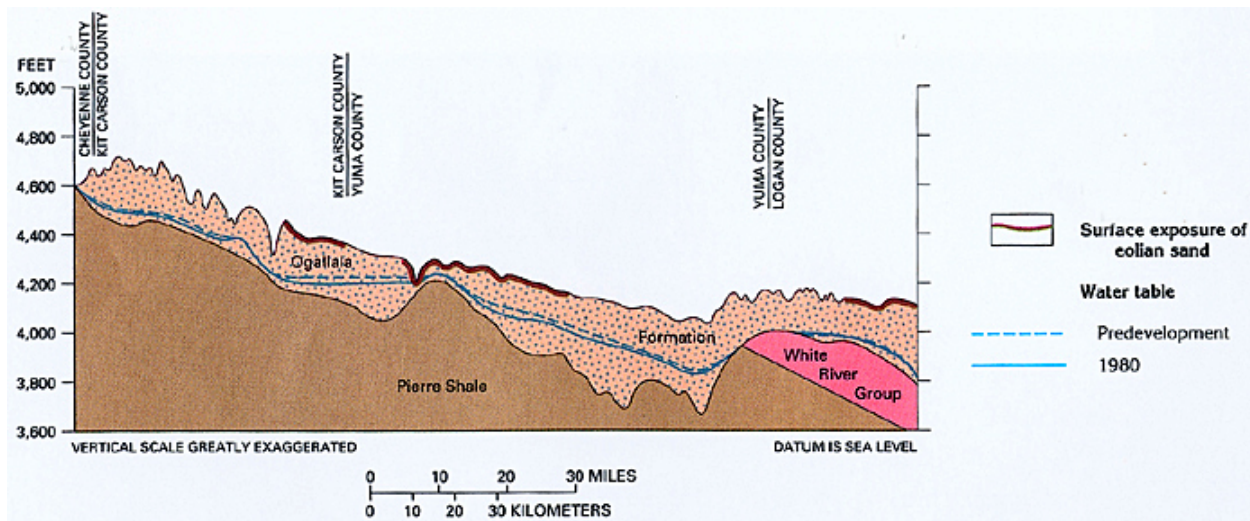


Figure 7. Decreasing depth of the High Plains Aquifer in the USA from predevelopment to 1980. It is deepest at the Ogallala Formation filling ancient stream channels in the bedrock. It is thinnest North-Eastern Colorado. Source: USGS.

In the Middle East, Iran is over-pumping its aquifers by an average of 5 billion m³ of water per year. Saudi Arabia, relying heavily on subsidies, developed an extensive irrigated agriculture, based on its deep fossil aquifer to produce wheat for export and are sucking it dry. Saudi Arabian farmers are pumping water from wells that are 4,000 feet deep. In the Yemen the water table under most of the country is falling by roughly 2 meters / year. In western Yemen's Sanaa's Basin, the estimated annual water extraction of 224 million tons far exceeds the annual recharge of 42 million tons. This drops the water table by 6 meters / year.

LAND SUBSIDENCE AND SALT WATER INTRUSION

When groundwater is depleted, land subsidence occurs when porous formations that once held water collapse, resulting in the surface layer settling. As the ground sinks or compacts, the aquifer's capacity in holding the same amount of water again, is lost. From 1986 to 1992 some parts of the Mexico City Aquifer's water levels dropped 6-10 meters. Areas of Mexico City, as a consequence, have fallen as much as 8.5 meters. The subsidence or ground compaction is damaging the sewer system, potentially leading to untreated sewage mixing with fresh water in the aquifer. In Mexico the demand for water is outstripping supply. In the agricultural state of Guanajuato the water table is falling by 2 meters or more per year.

In March 2009, Enoch City in Iron County, Cedar Valley Utah, contacted the Utah Geological Survey (UGS) about what they believed to be a fault running through one of their new subdivisions. It was determined by the UGS that it was a fissure caused by the groundwater level dropping as much as 114 feet since 1939 due to pumping more groundwater than is recharged.

When too much groundwater is pumped out from coastal aquifers, saltwater replaces it, causing a contamination of the fresh water in the aquifer. Coastal aquifers such as the Biscayne Aquifer near Miami, Florida and the New Jersey Coastal Plain aquifer have problems with saltwater intrusion.

Streams, rivers and lakes are usually closely connected with an aquifer. The depletion of the aquifers does not allow these surface waters to be recharged. Lowering water levels in the aquifers is being reflected in reduced amounts of water flowing at the surface to streams and lakes. This is happening along the Atlantic Coastal Plain in the USA. Groundwater depletion is also responsible for the Yellow River in China not reaching the ocean for months at a time, and the failure of the Colorado River in the USA and the Indus River in Pakistan to reach the oceans.

PEAK WATER, WATER MINING

The world may attain peak water ahead of peak oil. The world's underground aquifers could run dry as the melting glaciers play havoc with the fresh supplies of water. The world governments have been slow to accept the fact that water is running out. Fresh rainfall is not sufficient to refill the aquifers underground water tables.

According to Lord Nicholas Stern, the World Bank's former chief economist:

“The glaciers on the Himalayas are retreating and they are the sponge that holds the water back in the rainy season. We are facing the risk of extreme runoff, with water running straight into the Bay of Bengal and taking a lot of topsoil with it. A few hundred square miles of the Himalayas are the source for all the major rivers of Asia; the Ganges, the Yellow River, the Yangtze, where 3 billion people live. That is almost half the world's population. Water is not a renewable resource. People have been mining it without restraint because it has not been priced properly.”

In this regard, farming uses up to 70 percent of global water supply. Fresh water for irrigation is not returned to the underground basins since most is lost through leaks and evaporation. The investment banker Goldman Sachs suggested that water was the “petroleum for the next century,” with the USA alone needing up to \$1 trillion in new piping and waste-water treatment plants by 2020. According to the International Water Management Institute (IWMI): “Current estimates indicate that we will not have enough water to feed ourselves in 25 years time.”

WATER CONFLICTS

INTRODUCTION

Insightfully, Queen Elizabeth of England warned in March 2008: “The competition for fresh water by a growing population is itself becoming a source of potential conflict.”

The United Nations predicted that by 2020, water and not oil will be a source of conflicts around the world. One third of world will lack fresh water by 2025. In the USA, within that period, water will supplant energy as the most critical natural resource. Agricultural water is a target of thirsty cities, and farmers in the rural USA are far outnumbered by those who want it in its metropolitan areas.

Water wars are expected to be fought between rivals over the control of dwindling fresh water supplies in the 21st century. The English word “rival” comes from the Latin “rivalis” meaning “someone sharing a river.” According to the author Mark Twain, “Whiskey is for drinking. Water is for fighting over.”

The water wars have already flared up and are continuing in the Middle East around the Jordan River, the Hassabani and Litany Rivers in Southern Lebanon, and Lake Tiberius or the Sea of Galilee. Salinization is destroying the arable land in the Jordan River Valley inexorably destroying the livelihood of its population. The city of Amman, Jordan obtaining its fresh water supply from the distant Al Azrak oasis, suffers days of low water pressure due to excessive losses in the piping system. Vital aquifers in the Gaza Strip have been polluted causing health problems. Palestinians with yellow teeth are readily recognized and stereotyped as originating from the Gaza strip.

About 4,500 years ago conflict occurred between two Sumerian city states: Lagash and Umma over irrigation rights in what is today Iraq. The wars were recorded on a stone carving showing vultures flying off with the heads of the defeated Umma warriors.

International rivals sharing waters such as the Nile, the Tigris, the Euphrates, the Ganges or the Parana have so far favored cooperation over conflict, fully signing instead 3,600 international water treaties. The Indus River commission kept going despite wars between India and Pakistan. Israel and Jordan held secret talks about sharing the waters of the Jordan River since the 1950s.



Figure 8. Chinese-built dam on the Nile in the Sudan, and other dams under construction in the Sudan and Ethiopia, as a source of potential conflict between Sudan and Egypt.

Water shortages caused by increasing populations and climate change could trigger conflicts this century in a world where a billion people in the developing countries lack access to fresh drinking and irrigation water. Demand for fresh water could double by 2050, led by farming which absorbs 74 percent of all fresh water used by humans.

RENAISSANCE DAM, BLUE NILE WATER PUMPING

When complete, the Grand Renaissance Dam, which Ethiopia built, will be Africa's biggest hydroelectric power plant. Its construction began in 2011 on the Blue Nile tributary in the northern

Ethiopia highlands, from where 85% of the Nile's waters flow, 15 percent from the White Nile. However, the mega dam has caused a row between Egypt and Ethiopia, with Sudan caught in between. The Ethiopian dam is on the Blue Nile river, a tributary of the Nile. The Nile flood comes from the Blue Nile. The White Nile maintains the flow when the flood from the Blue Nile is low. The Sudd marsh in South Sudan is like a great sponge and contains the flow in the wet season in Central Africa, which "seeps" out during the dry season, maintaining the flow. The seasonal flood no longer affects lower Egypt, as it did previously, because of the Aswan dam.

At the center of the dispute are plans to fill up the mega dam as Egypt fears the project will allow Ethiopia to control the flow of Africa's longest river. Hydroelectric power stations do not consume water, but the speed with which Ethiopia fills up the dam's reservoir will affect the flow downstream. The longer it takes to fill the reservoir, which is going to be bigger than Greater London with a total capacity of 74 billion cubic meters, the less impact there will be on the level of the river. Ethiopia wants to do it in six years. But Egypt has proposed a longer period - so that the level of the river does not dramatically drop, especially in the initial phase of filling the reservoir. That new filling timetable requires filling the dam to take from 12 to 21 years.

Egypt relies on the Nile for 90 percent of its water. It has historically asserted that having a stable flow of the Nile waters is a matter of survival in a country where water is scarce. A 1929 treaty (and a subsequent one in 1959) gave Egypt and Sudan rights to nearly all of the Nile waters. The colonial-era document also gave Egypt veto powers over any projects by upstream countries that would affect its share of the waters. Neither agreement made any allowance for the water needs of the other riparian states that were not parties to the deal, including Ethiopia, whose Blue Nile contributes much of the river waters.

Ethiopia has said it should not be bound by the decades-old treaty and went ahead and started building its dam at the start of the Arab Spring in March 2011 without consulting Egypt. Egyptian President Abdul Fattah al-Sisi was quoted as saying that it would never have got under way had Egypt not been distracted by the political turmoil. One of the North African country's main concerns is that if the water flow drops it could affect Lake Nasser, the reservoir further downriver, behind Egypt's Aswan Dam, which produces most of Egypt's electricity. Egypt requests that the dam should be connected to the Aswan dam.

Egypt also fears that the dam could restrict its already scarce supply of the Nile waters, which is almost the only water source for its citizens. It could also affect transport on the Nile in Egypt if the water level is too low and affect the livelihood of farmers who depend on the water for irrigation.

The \$4bn (£3bn) dam is at the heart of Ethiopia's manufacturing and industrial dreams. When completed it is expected to be able to generate a massive 6,000 megawatts of electricity. Ethiopia has an acute shortage of electricity, with 65% of its population not connected to the grid. The energy generated will be enough to have its citizens connected and sell the surplus power to neighboring countries.

Ethiopia also sees the dam as a matter of national sovereignty. The dam project does not rely on external funding and relies on government bonds and private funds to pay for the project. The country has been critical of what it considers foreign interference in the matter.

Neighboring countries including Sudan, South Sudan, Kenya, Djibouti and Eritrea are likely to benefit from the power generated by the dam. Many of these countries have huge power deficits.

For Sudan there is the added advantage that the flow of the river would be regulated by the dam - meaning it would be the same all-year round. Usually the country suffers from serious flooding in August and September.

There have been fears that the countries could be drawn into a conflict should the dispute not be resolved. In 2013, there were reports of a secret recording showing Egyptian politicians proposing a range of hostile acts against Ethiopia over the building of the dam. President Al Sisi has also been quoted as saying that Egypt would take all the necessary measures to protect their rights to the Nile waters. It would threaten the vital international trade route through the Suez Canal and along the Horn of Africa, according to analysis by the Washington Institute.

STRATEGIC IMPLICATIONS

A handing over of the two Red Sea islands of Tiran and Sanafir by Egypt to Saudi Arabia is alleged to be a prelude for a water pipeline from the Nile River across the Red Sea via Saudi Arabia to Israel, thereby serving Israel's and Saudi Arabia's water shortages. That will impact Egyptian agriculture and possibly result in an Egyptian Ethiopian conflict in the future and possibly the break-up of Egypt into separate entities to enable the establishment of a greater Israel controlling the east bank of the Nile.

President Abdel Fattah El Sissi of Egypt handed over the Tiran and Sanafir Islands in June 2017 at the mouth of Gulf of Aqaba to Saudi Arabia in exchange for financial and military aid. The transfer had been discussed with, and had received the blessings of Israel, according to Israel's Defense minister Moshe Yaalon. Israel is involved in the planning of 40 dam projects along the Nile River. The implications of a possible Israeli-Saudi Arabian-Egyptian alliance or conflict are substantial.

The Grand Ethiopian Renaissance Dam was opposed by former President Mohammed Morsi. A great concern for Israel was President Mohammed Morsi's opposition to the construction of the dam. The construction was favored by Israel and Saudi Arabia.

In 2012, it was reported that Saudi Arabia had claimed a stake in the Nile. Israel's ambitions went much further back. First initiated by Theodore Herzl in 1903, the diversion plan was dropped due to British and Egyptian opposition to it only to be picked up again in the 1970s. At that time, Israeli's idea was to convince Egypt to divert Nile water to Israel. In 1978, President Anwar Al Sadat suggested in Haifa to the Israeli public that he would authorize transfer of Nile water to the Negev Desert. In a letter to Israeli Prime Minister Menachem Begin, President Anwar Al Sadat promised that Nile water would go to Jerusalem. During President Hosni Mubarak's presidency, published reports indicated that Israeli experts were helping Ethiopia to plan 40 dams along the Blue Nile River [17].

On May 30, 2013, The Times of Israel reported that the construction on the Grand Ethiopian Renaissance Dam on the Blue Nile had sparked a major diplomatic crisis with Egypt. The article also reported that Major General Mohammed Ali Bilal, the deputy chief of staff of the Egyptian Armed Forces, had said that Egypt was not in a position to confront the project countries: "The only solution lies in the USA intervening to convince Ethiopia to alleviate the impact of the dam on Egypt." On June 3, 2013 President Mohammed Morsi met with his cabinet to discuss the dam and its implications. The cabinet members were surprised to learn that the meeting was aired live. A cabinet member said: "Imagine what 80 million of us would do to Israel and America if our water was turned off". President Mohammed Morsi contended that: "We have very serious measures to protect every drop of Nile water."

Disagreements between Egypt and the other Nile River Basin countries, especially Ethiopia, have escalated following the insistence of Ethiopia's government on building the Renaissance Dam on the Nile, to which Egypt objects for fear that it might compromise Egyptian water security and reduce its share of water. Negotiations between technical committees from Egypt, Sudan and Ethiopia have failed to reach a clear understanding on the dam. Egypt refused in May 2010 to join the Entebbe Nile River Basin Initiative treaty, because it contained articles that did not recognize Egypt's historically established quotas of Nile waters and gave signatory states the right to build facilities on the Nile without consulting with downstream countries.

The Entebbe agreement states indirectly that the share of the downstream countries, namely Egypt and Sudan, could be reconsidered so that upstream countries, including Ethiopia, may receive a fair and reasonable share. The agreement does not refer to any rights for downstream countries to supervise water projects of upstream countries. The Entebbe Framework Convention was signed by Ethiopia, Rwanda, Burundi, Kenya, Tanzania and Uganda in May of 2011. Egypt, Sudan, South Sudan and the Democratic Republic of Congo did not sign the agreement.

It is essential for governments to negotiate and reach solutions to contentious water sharing issues, without creating political problems between the countries of the Nile Basin. Conflict must be avoided, when their peoples are suffering from poverty, hunger and disease, when they possess valuable water resources that can be shared for the benefit of all.





Figure 9. Renaissance dam on the Blue Nile, Ethiopia.

The Grand Ethiopian Renaissance Dam, formerly known as the Millennium Dam and sometimes referred to as Hidase Dam, is a gravity dam on the Blue Nile River in Ethiopia that has been under construction since 2011. It is in the Benishangul-Gumuz Region of Ethiopia, about 15 km (9 mi) east of the border with Sudan. At 6,450 MW, the dam will be the largest hydroelectric power plant in Africa, as well as the 7th largest in the world. Once completed, the reservoir will take from 5 to 15 years to fill with water.

The eventual site for the Grand Ethiopian Renaissance Dam was identified by the USA Bureau of Reclamation during a Blue Nile survey conducted between 1956 and 1964. The Ethiopian Government surveyed the site in October 2009 and August 2010. In November 2010, a design for the dam was submitted. On 31 March 2011, a day after the project was made public, a USA \$4.8 billion contract was awarded without competitive bidding to Salini Costruttori and the dam's foundation stone was laid on 2 April 2011 by then Prime Minister Meles Zenawi. A rock crushing plant has been constructed along with a small air strip for fast transportation.

Egypt, which lies downstream, opposes the dam which it believes will reduce the amount of water that it gets from the Nile. The dams will have three spillways. All three spillways together are designed for a flood of up to 1,360,000 cu ft/s, an event not considered to happen at all, as this discharge volume is the so-called 'Probable Maximum Flood'. All waters from the three spillways are designed to discharge into the Blue Nile before the river enters Sudanese territory. The main contractor is the Italian company Salini Costruttori, which also served as primary contractor for the Gilgel Gibe II, Gilgel Gibe III, and Tana Beles dams.

Violence over water can break out within countries over rivers, lakes, oases or wells. In Kenya, dozens of people died in 2006 from fighting between nomadic tribes over scant water and

grazing rights. A conflict between farmers and nomadic herding tribes has caused conflict leading to international intervention in the Darfur province of the Sudan.

The Tamil Tiger rebels were accused of shutting off sluices in Sri Lanka in their separatist war with the government forces. German and Saudi Arabian irrigation projects in the Sudan and Chinese dam projects in the Sudan are using Nile River water supplies and denying it to its historical users in Egypt. Dams being built in Ethiopia and the Sudan are seeding the sources of inevitable future conflict with other downstream users of the water.

Other countries vulnerable to water scarcity include Chad, Somalia, Lebanon, Syria, Jordan, Iraq, Turkey, as well as Egypt, Sudan, Ethiopia, Pakistan, India and China.

NORTH AMERICAN SHORTAGE

OVERVIEW

A water conflict has been looming since 2006 in the South USA. The state of Georgia has been “illegally” damming-up extra water to support a booming Atlanta population. This water would otherwise have flowed to cities in the neighboring states of Florida and Alabama. The Army Corps of Engineers failed to broker a negotiation between Georgia, Alabama and Florida and announced it will employ a water rationing plan handed down by the USA Federal government.

Lake Mead behind the Hoover Dam by Las Vegas, a source of water for 8 million people at the cities of Las Vegas, Los Angeles and San Diego in the South Western United States could go dry by 2021. The natural forces of evaporation, changes due to global climatic change and an increasing demand from the booming USA Southwest population are creating a deficit in this part of the Colorado River system. This also includes Lake Powell, which is on the border between Arizona and Utah.

The reality of chronic water shortage is overtaking the USA. Thirty six states are expected to face water shortages caused by rising global temperatures due to climatic change, drought, population growth, urban sprawl and wasteful use such as at car washes, amusement parks and golf courses.

In the summer of 2007, Georgia banned all outdoor watering. With the landscape paved over in Florida, water cannot recharge the aquifers, and to avoid flooding, water is flushed into the ocean.

In the West, California uses 23 trillion gallons of water per year, primarily originating from the Sierra Nevada Mountains snow melt. Climate change is causing less snow pack, melting it prematurely threatening future water availability.

The Colorado River is providing less water to 7 western states as climatic change is reducing its flow rate.

GREAT LAKES WATER

The Great Lakes contain 1/5 of the world’s fresh water resources. However, at the end of 2005 an agreement was signed by the Governments of eight USA Great Lake states: Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania and Wisconsin, together with Ontario and Québec from Canada. The pact bans new or increased water diversions outside the

drainage area and requires approval of major water diversions outside the Great Lakes watershed and regulates new commercial water uses.

This counters plans to move vast quantities of water from Canada, as the largest global freshwater supply holder, down to the USA western states. The McLean's Canadian magazine stirred up the issue by suggesting that Canada should sell water to the USA "before they take it." A former premier of the western Canadian province of Alberta has called upon its House of Commons to take a stand against any large scale water transfers to the USA. This could be a paranoid illusion anyway, since most of the excess water in Canada is in rivers that run to the north, away from the USA and the Canadian-USA border.

WESTERN WATER SUPPLIES

Western states on either side of the Rocky Mountains get little rainfall that is not sufficient to sustain crops. Dependence there for the irrigation of summer crops is on winter snowfall and the ensuing runoff from the snow pack.

The Western water supplies have been under increased pressure with the snow cover for the Northern Hemisphere down by 10 percent since 1966 as reported by The National Climate Data Center (NCDC). Less snow pack, faster warm up and quicker runoff in the spring are observed in the Western mountains, creating pressure on water reservoir operators who must balance flood control with water supply issues and forcing them to change their operational strategy.

AMERICAN CORN BELT WATER SUPPLIES

The American Corn Belt possesses two recharge patterns. For the Western Midwest states, rain from spring through fall accounts for most of the supply, with winters that are relatively dry from the Dakotas to Nebraska. It becomes critical for these states to recharge their water supplies from spring through fall. The Eastern Midwest states receive precipitation throughout the year, with drought relief occurring any time of the year. The Southeastern states like the eastern Corn Belt and the Eastern states get precipitation any time of the year with rainfall being more variable throughout the Southwest.

Extreme rainfall events as seen by the NDDC are leading to an increased variability. Total rainfall is relatively stable, but in some regions it is coming down in greater amounts less frequently, possibly caused by global climatic change. In the summer of 2007 a single storm system at Corpus Christi, Texas dropped 10 inches of rain in a day; the most that the city has received in a single day since record keeping began in 1887, even after exposure to several in hurricane events.

In the past three decades a warming trend has been observed in the USA, possibly contributing to a change in rainfall patterns with a higher incidence in heavy precipitation events. Water recharge is less efficient during these short heavy rain events than during a number of shorter showers and a slow soaking rain or melting snow. This limits the amount of moisture that reaches the subsoil and filters through to replenish the ground water supplies.

DROUGHTS INCIDENCE CYCLES

Tree rings studies indicate an increased probability of drought cycles with an average period of 18.6 years with a maximum value of 23 years suggesting a period of 18.6 ± 4.4 years. Iowa State University agricultural meteorologist Elwynn Taylor recounts the history of the two early British colonies established in the Roanoke Island area 20 years apart that may have perished because they coincided with the 18.6 years drought incidence period. The first colony at Roanoke Island was established around 1587. When the supply ships came to check on them the colonists were already gone. Another trial was attempted again at Jamestown in 1607 or $(1607 - 1587) = 20$ years later, with only 20 percent of the colonists surviving the attempt. The two colonies were established during two risky periods for droughts incidence according to the 18.6 years period, and the British had no way of knowing it with 1587 being the worst drought and 1607 being the second worse one over the last 800 years time span.

Another cycle is the 89 years warming and cooling phases known as the Gleisberg cycle related to the intensity of sunspots activity. A warming phase follows the sun's expansion in size, and a cooling phase is associated with its shrinkage.

An Ohio farmer, Samuel Benner, concerned about the relationship between weather and crop prices, in 1885 plotted the prices of grain and pig iron from 1800 to 1885. His plot revealed a regular pattern of droughty and heavy rain years within risky spans of 6 years durations each where their probability of occurrence increases. A prediction of a drought around 1953 came in 1955, a prediction around 1971 came in 1974 and a prediction around 1987 came in the last major drought of 1988-1989. There is no identifiable scientific basis for a cycle with a period of about:

$$\frac{(1974 - 1955) + (1989 - 1974)}{2} = \frac{19 + 15}{2} = 17 \text{ years.}$$

On this assumption, risky periods for drought spreads over a six years period may occur around the intervals:

$$(1989 + 17) \pm 3 = 2006 \pm 3 = [2003, 2009],$$

$$(1989 + 2 \times 17) \pm 3 = 2023 \pm 3 = [2020, 2026].$$

On the basis of tree rings studies, a higher risk for a drought with a risky span of $4.4 \times 2 = 8.8$ years would be predicted around the interval:

$$(1989 + 18.6) \pm 4.4 = 2007.6 \pm 4.4 \approx [2003, 2012].$$

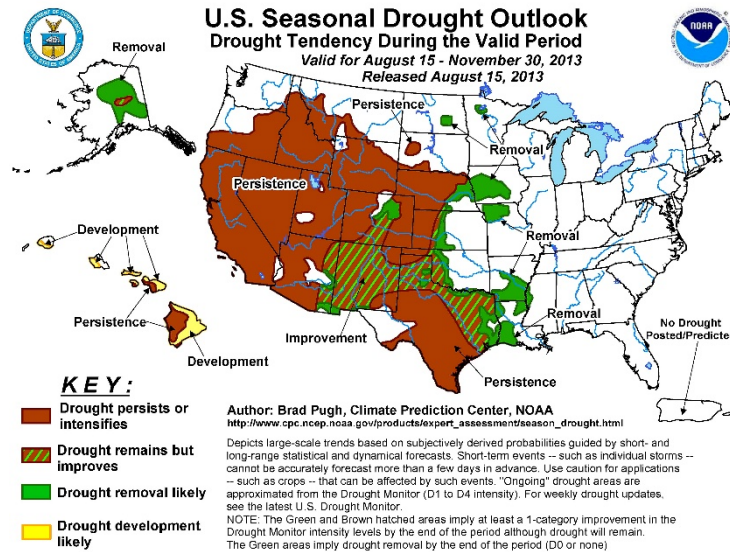


Figure 10. Palmer Drought Index, USA Seasonal Drought Outlook. Source: NOAA.

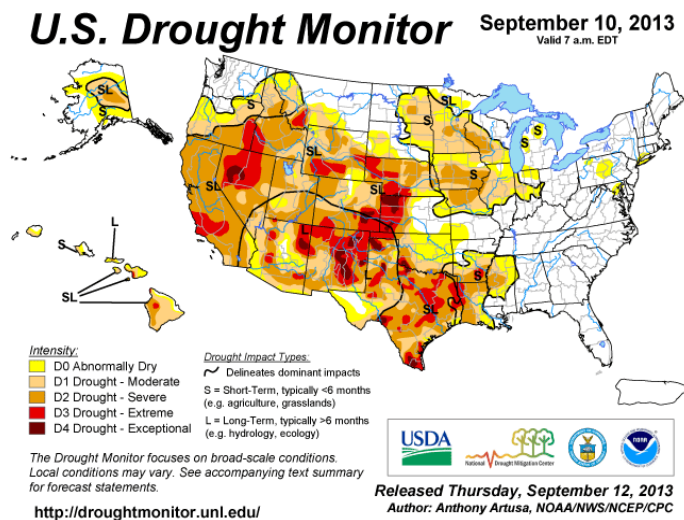


Figure 11. Palmer Drought Index, USA Seasonal Drought Monitor. Source: NOAA.

The drought of 2012-2013 in the USA could be a curious coincidence. The likelihood of droughts appears also related to weather oscillation phenomena such as the 11 years cycle of increased solar flares events, the El Niño (Little Boy in reference to Baby Jesus birth at Christmas time) larger than normal sea surface temperature heating of the eastern tropical South Pacific Ocean waters along South America about Christmas time, and its opposite La Niña (Little Girl) lower than normal cooling. The arrival of La Niña around Christmas-time signals an increased probability of twice than average of a drought in the American Corn Belt if the condition persists into the month of May like in the 1988-1989 drought.

The worst droughts of each century occurred during periods of global warming such as the one in 1847 and the American Dust Bowl around 1936. The period here is $1936 - 1847 = 89$ years,

thus according to this cycle the next major drought of Dust Bowl proportion would be due around the year $1936 + 89 = 2025$.

WATER DEPLETION AND SHORTAGE CONFLICTS

Low water flows in 2007 in the South Platte River triggered the shutdown of 440 irrigation wells at Wiggins, Colorado for non compliance with the existing pumping regulations. Millions of dollars worth of wheat, corn, sugar beets and melons withered and died for the benefit of supplying municipal water to Boulder, Colorado and other sprawling cities. A drought in the American West, an explosion in the construction of ethanol plants, sharply higher corn prices, and the scepter of climate change are raising the stakes.

The Ogallala Aquifer, the world's largest underground water system, is used for irrigation in the drought plagued regions of the USA High Plains. It irrigates 1/3 of the USA corn crop and provides the drinking water for 8 states. In parts of western Kansas, hydrologists report that the water table was reduced by 25 feet in the last decade. Their estimate is that the aquifer, without significant recharge, would dry up within 25 years.

The depletion of the Ogallala Aquifer is more serious in Texas. There, the Rio Grande River is over-allocated in owned water rights from its headwaters to the Gulf of Mexico. Decades-old legal compacts to share the water are resurfacing in the courts among the adjoining states through which it flows. A 2002 settlement of a lawsuit by Kansas against Nebraska about using more than its allocated share of the Republican River drives the legislative agenda in Nebraska, which is considering imposing water conservation fees on irrigated land and municipal water systems.

Irrigated acres are shrinking in seven states which rely on the Colorado River: Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming. They all lost irrigated land from 1997 to 2002.

Urban areas are a major user of fresh water. Arizona's population has increased by 40 percent since 1990. Colorado's population grew by 30 percent over the same period.

A tug of war has been ongoing in the courts for 15 years between the navigation, recreation and environmental groups, preventing the USA Corps of Engineers from carrying out a plan for managing the Missouri River. States cannot meet the Endangered Species Act rules because of insufficient river and stream flows.

The state of Montana sued the state of Wyoming in the USA's Supreme Court on February 2007 over water rights in two shared rivers, which Montana claims are running dry due to Wyoming's overuse. The lawsuit over the Tongue and Powder rivers, which flow from north eastern Wyoming into south eastern Montana, marks a sharp escalation in the water fight between the states. The lawsuit alleges Wyoming is ignoring Montana's senior water rights by taking more water from the rivers than allowed under the 1950 Yellowstone River Compact. That includes water diverted and stored for irrigation and ground water pumped from beneath the surface during coal bed methane production. Both states have suffered from a prolonged drought dating to 1999. In recent years due to the drought, only a small fraction of Wyoming's water users in the Powder River and Tongue River basins received the water they needed. Flying over the border region between them reveals a sharp contrast: green on the Wyoming side, and brown in Montana.

GLOBAL SHORTAGE

The UN Intergovernmental Panel on Climatic Change suggests that by 2050, 2 billion people worldwide would face severe water shortages.

Australia has been suffering a 30 years dry spell. Population growth in sub Saharan Africa urban centers is straining its water resources. Asia with 60 percent of the world's population has only 30 percent of its fresh water resources.

In the Middle East, a conflict already exists about the control of the waters of the Jordan River and Lake Tiberius or the Sea of Galilee. The diversion of the Jordan River water through pumping to supply the water needs of the coastal cities of Israel then to the Negev Desert for irrigation is causing salinization on the West Bank of the Jordan River with the eventual desertification of the land.

A simmering conflict is arising about Turkey's damming the waters of the Euphrates and Tigris Rivers and preventing them from reaching Iraq.

Dam and irrigation projects financed by the petrodollars states in Ethiopia and the Sudan on the Nile River are bound deprive the large population of Egypt of its historical fresh water supply since antiquity, leading to assured future conflict.

In the five decades to 1999 there have been 37 military acts over water between states, with 30 out of them involving Israel and its neighbors Jordan, Syria and Lebanon. Israel in the 1960s destroyed Syrian pumping stations on the headwaters of the Jordan River at Lake Al Hola, seized and continuously occupied the Golan Heights from Syria since 1967, and using its own pumping stations, diverted the Jordan River water flow to a 1 meter in diameter "Conveyor Trunk Pipeline" supplying its Mediterranean coastal cities such as Haifa and Tel Aviv and then all the way to its agricultural projects in the Negev desert.

CHINA'S WATER SHORTAGE

In China two out of every three major cities have less water than they need. Cities in Northeast China have roughly 5-7 years left before they run completely dry. Through the process of desertification, the Gobi Desert devours 2,460 square miles of Chinese soil, an area roughly the size of the USA state of Delaware each year. China's rapid economic growth comes at a great price since air pollution inhibits precipitation: on hazy days, precipitation from the top of Mount Hua in China's northwestern Shaanxi province is cut by up to 50 percent. As a result 1/4 of China is buried beneath sand.

Another problem is that 90 percent of China's city aquifers are deemed polluted. Seven hundred million Chinese drink water contaminated with either animal or human waste.

China can be considered as an example of what is happening in other parts of the developing world. China is home to 20 percent of the world's total population; but just 7 percent of the globe's fresh water supply is available in China.

A lack of water, and not a shortage of energy, could throw a monkey wrench into China's economic engine and its 9 percent economical growth rate. In addition to drought and polluted ground water, it suffers from salt tides caused by drought and fresh water overuse that threaten the water supplies in southern China. With over 1/5 of the world's total population sharing only 7 percent of the fresh water on Earth, China has been listed by the UN as one of the 13 countries with the lowest water per capita usage in the world. Most of the country's waters are so polluted by industrial and mining waste as well as urban waste and sewage that they cannot support aquatic life, much less human life. Farmers in China are foregoing millions of tons of grain production every year. The per capita availability of water is expected to shrink to alarming levels by 2030.

In China, streams and rivers are drying up all over the northern half of the country, and water tables are falling precipitously. Many of the water wells are dug illegally and are sunk deeper into the dwindling reserves of groundwater aquifers. Some 400 out of 668 large Chinese cities are short of potable water, and rationing is growing in scope.

Pollution of the water supply is becoming a cause of major concern. The Chinese industrial machine, particularly the burning of coal, releases around 600 tons of toxic mercury (Hg) into the atmosphere each year, accounting for nearly 1/4 of the world's non natural emissions. The Hg emissions are so destructively ubiquitous that the USA Environmental Protection Agency (EPA) has warned that 1/3 of the USA's lakes and 1/4 of its rivers are now so polluted with Hg that children and pregnant women are advised to limit or avoid eating fish caught there. Fully 1/3 of the Hg deposition in the USA originates from the Chinese emissions.

Half of China's population consumes drinking water contaminated with animal and human waste that exceeds permissible levels in industrialized nations, with the result that China has the highest liver and stomach cancer death rates in the world. Two thirds of China's 600 largest cities do not have enough water; and half of these cities have polluted groundwater. Less than 15 percent of China's population has safe tap drinking water. Clean water is the ultimate China and world health consideration since no economy can flourish for long by polluting the water that sustains its work force.

To provide fresh water supplies, the Chinese government established "Weather modification offices" for cloud seeding that use rocket launchers and airplanes loaded with silver iodide (AgI) or carbon dioxide (CO₂) crystals that are seeded directly into the clouds formations. Those crystals that are used in cloud seeding have the same structure as the natural ice crystals and, under the right atmospheric conditions below the saturation pressure and temperature of water, can act as nucleation sites for water droplets, then ice, and generate artificial rainfall. The need is not so much for drinkable water but more so for a need to irrigate the massive agricultural land producing the food supply needed to feed roughly 1/5 of all humanity. Around 1/2 of China's landmass is uninhabited, so the existing farmland must be utilized to its full capacity.

Social stability is also a major consideration. China cannot afford another major famine such as the one that occurred after the 1960s Mao Tse Tung's Great Leap Forward whose turmoil is reported to have been associated with the loss of the lives of more than 30 million persons. A similar disaster occurred in the 1940s where about 3 million farmers in the Henan Province succumbed to starvation.

The situation in India is not much different. One sixth of India's food output is being supported by pumping groundwater, which is depleting rapidly. In the state of Tamil Nadu, more than 1/3 of the aquifers are over exploited, with the rate at which water is being extracted is more than the pace of recharge. By the World Bank's estimates, by 2050 demand for water in India will exceed all available supplies.

China and India, which are going dry, will be forced to import more food. As urbanization gathers momentum, many farmers in India are selling their water entitlements to condominium and factory owners. When two of the World's top three grain producers become importers of grain, this will have a notable impact on food prices internationally.

For countries and peoples whose history is punctuated with periods of drought and starvation, and within the last century alone, witnessed the loss of life of nearly 40 million humans, fresh water becomes the most precious of any commodity.

Every populous country in the world will be committing large resources over the next 20 years to install and upgrade its water and waste water infrastructure. The USA needs to spend \$1 trillion over the next two decades to upgrade its water infrastructure.

DESERTIFICATION AND SALINIZATION

Spreading deserts and degradation of farm land due to climate change will pose a serious threat to food supplies for the world's surging population in coming years, as all continents see more weather related disasters like heat waves, floods, landslides and wildfires.

The present world population of 6.3 billion is being fed from the 11 per cent of the land surface that can be used for serious food production. If less farmland is available, it will be difficult to feed the 8.2 billion expected to populate the globe in 2020.

Africa, Latin America and parts of Asia, where the climate is already more extreme and arid regions are common, will be most affected as rainfall declines and its timing becomes less predictable, making water scarcer. Europe, particularly around the Mediterranean, would also suffer from heat waves.

Declining rainfall and evaporation of water supplies could also mean less was available for irrigation and for generating electricity for farm machinery, causing lower crop productivity.

In some regions such as the Caspian Sea and the West Bank of the Jordan River, the spread of deserts and the salinization of once arable land is already well underway. In the future it would be most widespread in drier areas of Latin America, including in Brazil.

In Africa, increasing climate variability would create major problems for farmers, who are likely to see their growing seasons getting shorter and crop yields cut, especially in areas near already arid and semi-arid regions. An example is the inexorable shrinkage in the size of Lake Chad and the conflict between grazing nomads and irrigation farmers in the Darfur region of the Sudan.

FRESH WATER STATISTICS, LINKAGE TO ENERGY AND FOOD PRODUCTION

The rising struggle for fresh water has the potential to escalate to a magnitude similar to the current geopolitical conflicts over energy supplies.

The big five food and beverage companies use 150 billion gallons of water per year. This is enough to satisfy the daily water needs of every person on Earth.

In Silicon Valley, California, 25 percent of the water use is for making computer chips. In the USA, 40 percent of the water drawn from lakes and aquifers goes toward cooling power plants. The link between water and energy is strong and largely unappreciated.

It is publicized that it takes about 1 gallon of water to make 1 gallon of food product. That understates true water usage, though, because it does not factor in the amount of water needed to produce the food products used as raw materials. The more realistic figure is that it takes about 793 gallons of water for the production of 1 gallon of food product.

There is currently an ongoing war for the control of fresh water going on all over the world at the corporate level hashing out strategies at treatment facilities and offices. For instance, savvy subsidiaries of German companies such as the Illinois American Water Company control the water supply and treatment facilities in the USA such as the Mahomet Aquifer in Central Illinois in the USA. Around the twin cities of Champaign-Urbana, the 3,000-10,000 years old fossil water dating

back to the last glaciations period, is pumped out, dumped into the Kaskaskia drainage ditch which becomes the Kaskaskia River, and is conveyed downstream south to the water short cities of Tuscola and Arcola to feed their chemical plants.

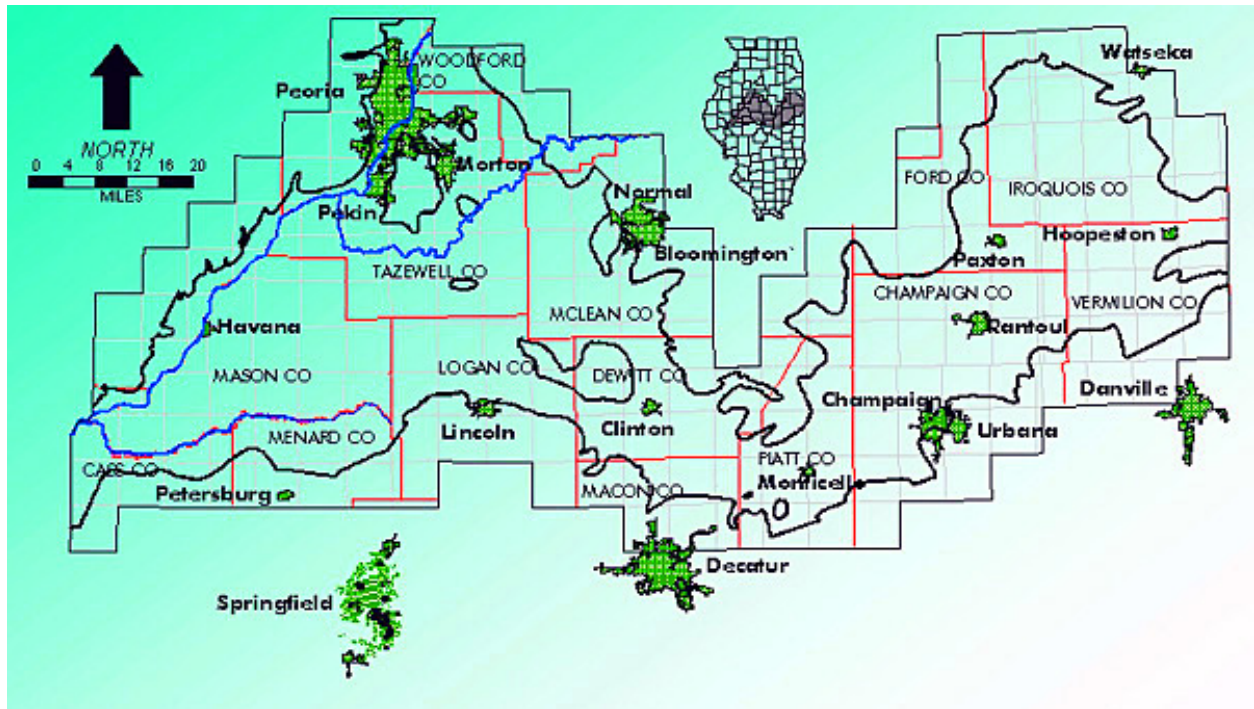


Figure 12. Extent of the Mahomet Aquifer in Central Illinois, USA. Source: Illinois Water Survey.

Electrical utilities that could not obtain permits to build power plants on the East coast of the USA, such as Public Service Enterprise Group (PSEG) from New Jersey are building gas turbine power plants in the Midwest and connecting them to the national power grid, then “railroading” or “dispatching” the generated power back to the East. A project to build such a power plant at water poor Sidney, Illinois, east of Champaign-Urbana would obtain its plant coolant needs by pumping the aquifer water through a pipeline to Sidney, providing tax dollars revenue to the city. There are plans to use the aquifer water to provide the needs of projected corn ethanol production plants which would use 6-10 gallons of water per gallon of produced ethanol, as well as for a coal gasification plant using a futuristic name: Future-Gen, exposing the aquifer with potential rapid depletion in addition to possible pollution by what are essentially industrial processes.

Two areas in the State of Illinois have been identified as at risk for water shortages and conflicts: the North East Illinois Deep Aquifer and the Mahomet Aquifer. The twin city of Champaign-Urbana in Central Illinois obtains its water from the Mahomet aquifer; a 3,700 square miles area of water saturated gravel and sand, but is reaching its local yield capacity. The aquifer is held by a bed rock on the sides and bottom and topped by impervious clay rich glacial till. It extends from the city of Danville on the Indiana and Illinois border to the south east of Tazewell County in Illinois. The recharge of the aquifer occurs at the rate of about one inch per year of water movement, completing its recharge function with a time constant of 3,000 years. Even though ground water is a renewable resource, it is not an infinite resource. It is finite in size and can be

depleted by over pumping which lowers the water table. Continued growth and withdrawal from the same part of the aquifer would lead to “dewatering,” a situation that would compromise the quality of water in the aquifer. Precluding climate change and population growth and urbanization under the present conditions, the Illinois State Water Survey (ISWS) estimates that an additional 16-17 million gallons per day can be pumped before starting to “dewater” the aquifer.

The manufacture of ethanol requires 6-10 gallons of water per gallon of ethanol. Most manufacturing processes use water in some form or another: 62,000 gallons per ton of steel and 39,000 gallons per average automobile. A typical ethanol plant producing 100,000 gallons of ethanol per day would need 600,000-1,000,000 gallons per day of water. Ethanol plants are contemplated around the cities of Royal, Tuscola, Farmer City, Champaign and elsewhere in the state of Illinois. The Ohio based company: The Andersons, is planning a plant in Champaign that would withdraw 1.9 million gallons of aquifer water per day by its grain elevator, bringing 35 jobs to the county. The company owns the mineral rights under its property according to state law and is entitled to withdraw that water. Under “reasonable use” standards water rights come with property rights, unless challenged in court. The courts would listen to the competing claims of the current users. A fraction of the withdrawn water would be discharged into the Kaskaskia River after being used in the ethanol fermentation and evaporative cooling processes and the company needs only the granting of a pollution permit for waste water discharge from the Environmental Protection Agency (EPA) to proceed with its project.

As water resources become scarcer, in the water wars the losers will have to move or face death, with the winners prospering and surviving. One billion people or about 1/6 of humanity, lack access to safe drinking water, and 1/3 of the world population people lives in regions with water scarcity.

Agriculture absorbs 74 percent of all water taken by humans from rivers, lakes, aquifers and wetlands against 18 percent for industry and 8 percent for municipalities. Demand for water is rocketing with a rising population. In many places, 30-40 percent of water is lost because of leaks in pipes and canals and illegal tapping into them.

Governments set a Millennium Goal in 2000 of halving the proportion of people with no access to safe drinking water by 2015. Diarrhea and malaria, the main water related diseases, killed 1.8 million and 1.3 million people respectively in 2002, with most of them children under the age of five. Achieving the 2015 drinking water goal would require \$10-\$30 billion extra a year on top of the amounts already invested.

The amount of water needed for crop production is projected to rise by 60-90 percent by 2050, to 11,000-13,500 km³ from 7,200 km³ in 2006. One calorie of food needs about a liter of fresh water to produce. The typical food consumption is 3,000 calories per day per person, or 3,000 liters of water. A kilogram (kg) of grain takes 500-4,000 liters to produce, and a kg of industrially produced meat uses 10,000 liters. The rising production of biofuels from crops such as corn, soybeans or sugar cane will complicate the efforts to feed the world and may add strains to irrigation, increase soil erosion and deplete fresh water supplies. For instance, it is estimated that it takes 6 gallons of water to produce one gallon of corn ethanol.

WATER AND HEALTH

Clean and safe drinking water is one of the greatest scientific achievements of the twentieth century. The Center for Disease Control (CDC) estimates that it extends present day Americans

life span by 30 years longer than their grandparents. The average American uses 2 gallons of water every time he brushes his teeth.

On the other hand, half of all hospital beds in the world are occupied by patients suffering from a water related disease. In the developing nations, 80 percent of all diseases stem from consumption of and exposure to unsafe water.

In Wisconsin's Calumet County, a porous karst bedrock is a conduit for pollutants to infiltrate the aquifers, springs and wells resulting in that half of 1,200 wells tested since 2002 had unsafe levels of nitrates and bacteria. Nitrates cause health issues for farmers as well as their animals. The "blue babies" syndrome is attributed to babies and toddlers drinking water with high nitrate levels. High levels of bacteria in well water can keep farmers from being able to market their cows' milk. Animal agriculture needs new procedures for immediate soil incorporation of manure and restricting winter spreading on frozen ground in high risk areas. In the state of Iowa new limits apply to liquid manure application on soybean and corn fields for farmers who are required to have manure management plans.

There is no shortage of water on our water planet, but there exists an acute shortage of fresh clean water. Contaminated water is deadlier than any other evil on Earth. During World War II, one soldier died every 5 seconds. Today, one human being dies every 3.5 seconds from drinking contaminated water.

More than one third of the Earth's population lacks access to effective sanitation, which is why more than a billion people contract water related diseases every year. The United Nations (UN) estimates that in less than 25 years, if present water consumption trends continue, 5 billion people will be living in areas where it will be impossible, or nearly impossible, to meet basic water needs for sanitation, cooking and drinking.

CAUSES OF WATER SHORTAGE

The water shortage crisis has several causes. Natural climatic aridity exists in many regions of the world such as the Sahara Desert and Australia. There is an ever present need to bring arid areas, particularly along ocean shores into cultivation so that the world's growing population could be fed. In some other areas with available water resources, rivers and lakes have been subject to overuse and pollution from industrial, agricultural discharges and municipal waste. The pressing need to overcome the difficulties imposed by urban life and industrial development where humans are amassed in tightly packed communities and discharging massive quantities of wastes, presents an unprecedented demand on the natural sources of fresh water supply and pollutes them at an alarming pace.

Many underground water reservoirs which are not being currently recharged are being depleted for commercial use such as the Ogallala Aquifer in the USA. Even those aquifers that are being recharged by rain are being stressed for industrial use such as power and chemical plants at a faster rate than they are being recharged. Much of the inland water deficiency is met by mining groundwater by pumping from deep wells. In the interior valleys of Arizona and California the ground water tables which is the level at which fresh water lies have dropped as much as several hundred feet creating a critical situation in some places

More than 7,500 desalination plants are in operation worldwide. Sixty percent of these are located in the Middle East. The largest plant in the world is in Saudi Arabia and produces 128 million gallons per day (mgd) of desalted water. Twelve percent of the world's capacity is produced in the Americas, with most of the plants located in the Caribbean and Florida, USA.

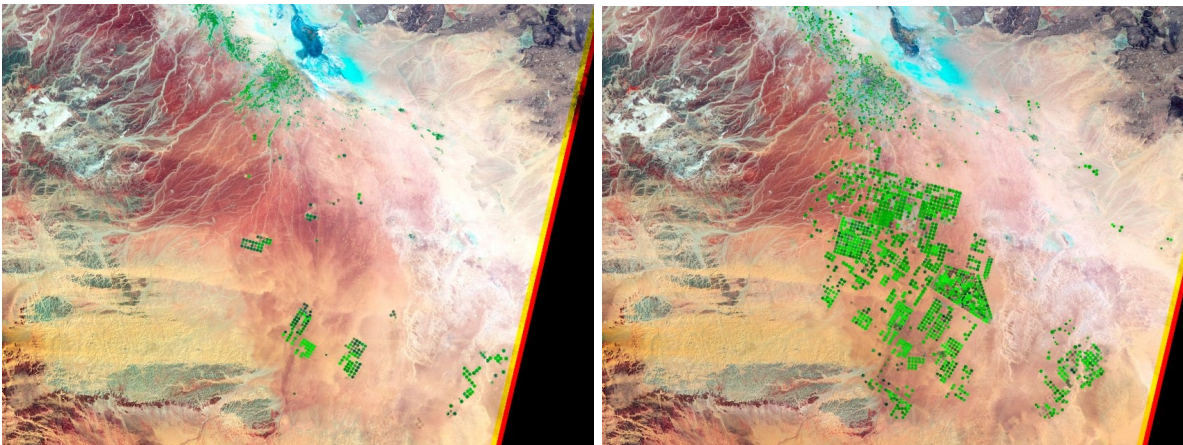
The USA National Research Council considered the possible effects of global climatic change. Its data signaled a warmer future with extended droughts for the Colorado River basin. The summer of 2006 was the second warmest in the USA since 1895. Drought plans have been drawn by 38 states compared with 3 in 1982.

Attempts at conserving existing water resources include suggestions to coat the surface of lakes and reservoirs with a substance to reduce evaporation. Heavy runoff could be diverted away from the sea to gravel and sand beds through which water seeps to raise the water table. Conservation in the use of municipal water supplies, by recycling, locating pipe leaks and reduced usage in agriculture by lining the sides of canals and the use of drip irrigation can extend the availability of fresh water supplies. At some point when conservation methods are exhausted, augmentation methods using solar, wind and nuclear energy sources are becoming indispensable.

When mentioning modern technology, it is humbling to remember that about 4,000 years ago, the Ancient Egyptians under the reign of Pharaoh Amenemhat III built a retaining wall 30 feet in height and 27 miles in length to enclose Lake Fayoum south of Cairo, Egypt so that 27,000 acres of desert land could be irrigated with the stored fresh water.

FOSSIL AQUIFERS DEPLETION

The Middle East and North Africa suffer from acute water shortages and pump millions of gallons per day from ancient fossil unreplenished aquifers. The water contains high levels of naturally-occurring radioactive contamination such as radium and radon gas posing a health risk to millions of people.



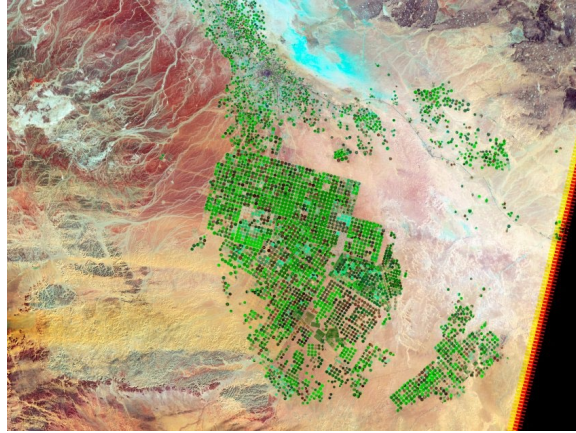


Figure 13. Expansion of central pivot irrigation systems at Wadi Al Sirhan fossil aquifer basin, Saudi Arabia in February 1991, March 2000, and January 2012 photos. Notice the depleted lake area at the top of the photographs. Source: NASA.





Figure 14. The Nubian sandstone aquifer under Egypt, Lybia and the Sudan stores as much fossil million-year old fresh water as the North American Great Lakes. Other Saharan aquifers identified by ground penetrating radar.

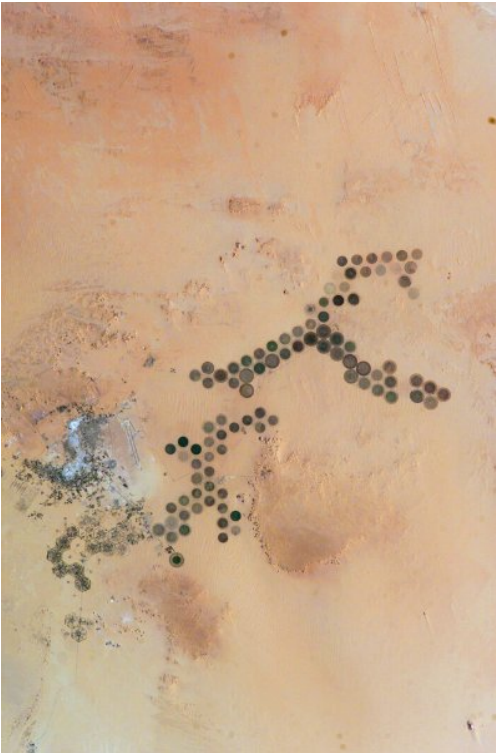


Figure 15. Al Khufra oasis, Lybia part of the Great Man-made River project showing central pivot irrigation systems, 2004. Source: NASA.



Figure 16. Idyllic picture of Um Al Maa, Arabic for “Mother of Water” lake in the Ubari Sand Sea, Lybia, 2008.



Figure 17. Dying palm trees at the Siwa Oasis, Egypt.

The Nabatean prehistoric civilization, precursor to the Arab culture mastered water management in the desert. They carved their capital city of Petra out of sandstone cliffs as a trading post for trade caravans. They built a sophisticated system of water pipes and cisterns 2,000 years ago.

Every day, millions of cubic meters of fossil unreplenished water are being pumped in the Middle East and North Africa. A hydraulic engineering project in Jordan, at a cost of \$1.1 billion or €850 million starting in the spring of 2013 pumps about 100 million cubic meters a year out of

the Disi aquifer in the country's south, in addition to the 60 million cubic meters a year already being taken from the aquifer today. The water will then be pumped through pipelines to the capital Amman, some 325 kilometers or 203 miles away.

HEALTH PHYSICS CONSIDERATIONS

Health physicists suggest that tests revealed that the aquifers water contains high levels of naturally occurring radioactivity, with samples exhibiting radiation levels 30 times above the World Health Organization (WHO) radiation safety standards. The health risk affects all of the countries in the Middle East and North Africa.

A study published in February 2009 by geochemist Avner Vengosh of Duke University in Durham, North Carolina, had tested radioactivity levels in 37 samples from the Disi aquifer in Jordan. According to the findings, published in the journal *Environmental Science and Technology*, the water from the aquifer, which is about 30,000 years old, is up to 30 times as radioactive as the World Health Organization (WHO) considers as a safe level.

The radioactivity is caused by the natural uranium and thorium decay chains elements that can occur in sedimentary rock. Their decay products include radium, which can cause bone cancer if it enters the human body. Two isotopes, Ra^{226} and Ra^{228} , with half-lives of 1,600 years and less than six years, respectively, are of concern.

The German Federal Office for Radiation Protection (BfS) calculated the magnitude of the health risk. A person drinking 2 liters of water per day from the Disi aquifer is exposed to radiation levels of 0.99 - 1.53 millisieverts / year, or 10 to 15 times as much as WHO considers safe. If we assume that the population receives an average annual dose of one millisievert and has an average life expectancy of 70 years, the radioactive drinking water will increase the normal number of deaths by four people per 1,000. When this estimate is extrapolated to the roughly two million residents of Amman, who are to be supplied with drinking water from the Disi aquifer in the future, it comes to about 8,000 additional deaths. The calculation only applies to the absorption of radium that occurs when people drink the water, without taking into account other ways in which radiation can enter the body, such as when the water is used to irrigate fields and radiation becomes concentrated in fruits and vegetables.

The same geological conditions that make the water from the Disi aquifer radioactive prevail in large parts of the Middle East and North Africa affects a large population. Only 10 percent of the Disi aquifer passes through Jordanian territory. The rest is in Saudi Arabia, where it's called the Saq aquifer. BRGM, the French national geological service, took samples from 64 locations in the aquifer. According to a report published in 2008, the radioactivity levels were generally well above the WHO guidelines. In its research, the BRGM encountered a strange phenomenon: Contamination with radionuclides appears to be especially high in places where the water level in the aquifers is declining the most precipitously, threatening to become unfit for both human consumption and agricultural use.

Fossil groundwater is essential for the survival of agriculture in the region. The amount of water being pumped from the Saq aquifer increased more than fourfold from 1985 to 2005, from about two billion to more than 8.7 billion cubic meters per year. Saudi Arabia already derives about half of its water from aquifers.

Israel pumps water from fossil reservoirs to irrigate its fields in the Negev Desert, and Egypt has pumped fossil groundwater in oases since the 1980s. Libya operates the world's largest pumping operation, the "Great Man-Made River." Every day, about 1.6 million cubic meters of

water are pumped from the Nubian Sandstone Aquifer System, at a rate of more than 18,500 liters per second. The massive system of wells, pipelines and reservoirs is conducting 6.5 million cubic meters of water a day from the desert to Libya's coastal cities. The other aquifers are heavily depleted that they are becoming brackish as a result of seawater infiltration, a problem that also plagues other coastal cities in the region.

Saudi Arabia is treating fossil groundwater and removing radioactive particles, but elsewhere, especially in rural parts of North Africa, water treatment technologies are lacking. The Jordanian Ministry of Water and Irrigation plans to dilute the water with water from sources with no radioactivity, which would reduce the annual radiation exposure to 0.4 millisieverts. That dose is four times as high as the WHO standard, and will be very difficult to achieve. An internal document produced by Germany's Federal Institute for Geosciences and Natural Resources (BGR), the Jordanians measured radioactivity levels in a part of the Disi aquifer where radium activity is especially low. Most of the water, however, is to be obtained from a part of the aquifer where radiation levels are much higher. According to the BGR, it would take the addition of at least one billion cubic meters of non-contaminated water a year to bring exposure to levels below the WHO standard. It is unclear where this much water would come from.

One of the largest financial backers of the Disi project is the European Investment Bank (EIB), which approved loans totaling \$225 million in May 2009. In its contracts with the EIB, Jordan pledged to begin testing the water from every well during the construction phase, and to submit regular reports. If Jordan failed to fulfill this obligation, the EIB could revoke the loan in an extreme situation.

Signs of the possible health consequences are apparent. In 2010, King Saud University examined 10 men who change filters in underground wells. Their blood was found to contain 11 times as much chromosomal damage than that of controls, in an article in the journal *Radiation Protection Dosimetry*.

Nevertheless, the use of fossil water could end up being the lesser of two evils. Although some of the water contains high radiation levels, it is considered very clean and free of bacteria. Consuming water of lesser biological quality would lead to more deaths than those resulting from radiation, partly from elevated numbers of diarrheal infant disease.

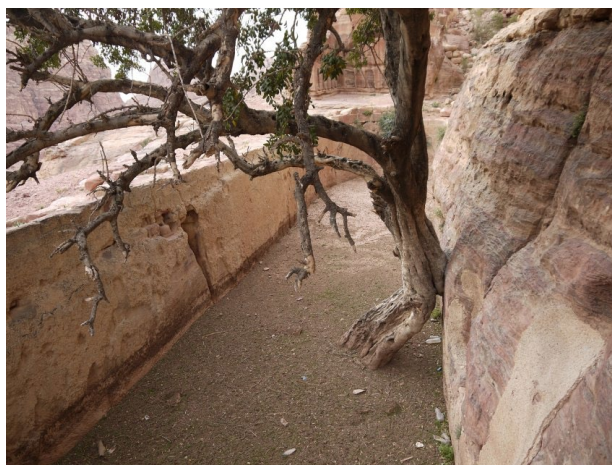


Figure 18. Water cistern at prehistoric Petra, part of the Nabatean civilization, precursor to the Arab culture.



Figure 19. The Dead Sea at Jordan is no longer being replenished by the Jordan River water, pausing an ecological problem.

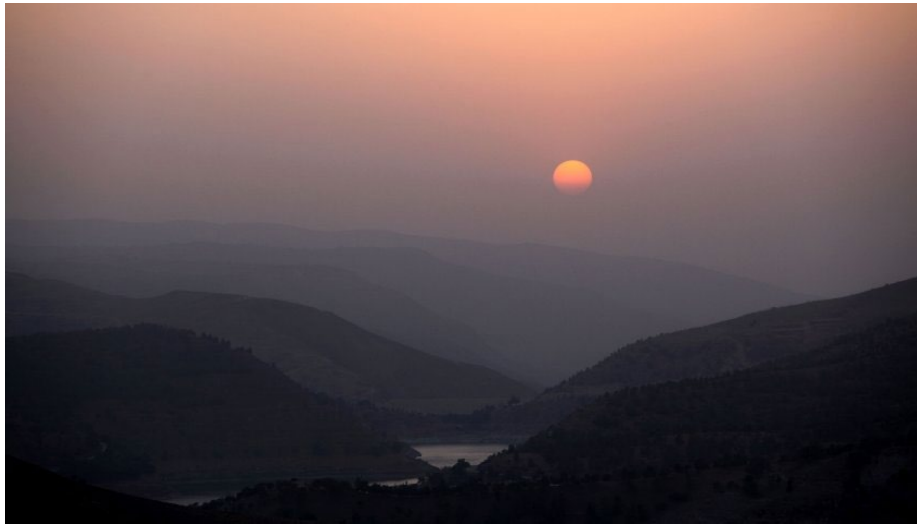


Figure 20. King Talal dam and artificial lake on Al Zarka, Arabic for “The Blue” River, Jordan.

NECESSITY OF FRESH WATER

About 70 percent of the Earth’s surface is covered with water. There is a tremendous volume of 324 million cubic miles of it. It contains 3.5 percent of salt and is useless as drinking water since humans can only tolerate 0.2 percent salt content. Beyond that level, the salt burden is more than the human kidneys can filter and secrete in urine. The body becomes dehydrated in its effort to rid itself of the excess salt. The purer the water, the better, although our taste buds do not like absolutely pure water and prefer water with a slight mineral content.

Only 0.3 percent of total water on Earth is fresh water. In about 1,000 communities in the USA the water is classified as brackish (Table 2). The water tastes harsh and bitter even though its salt concentration is within the body’s tolerance. In these communities people are dependent upon bottled drinking water, or have to haul-in potable water over long distances.

Table 2. Water Quality Classification.

Classification	Properties
Fresh	Contains less than 1,000 dissolved parts of salt per million parts of water (ppm).
Brackish	Ranges from 1,000 ppm up to the dissolved salt content of sea water. Mildly Brackish: 1,000 - 5,000 ppm Moderately Brackish: 5,000 - 15,000 ppm Heavily Brackish: 15,000 - 35,000 ppm
Seawater	About 35,000 ppm.
Brine	Larger dissolved salts than sea water. Examples: Great Salt Lake, Utah, USA. Dead Sea, Middle East.

ppm = parts per million, 10^{-6} .

WATER RESOURCES

Most of the world's water exists in the oceans, seas and the Antarctic Ice sheet. The Earth can be aptly called a water planet. On land, most of the water exists underground as fresh, brackish water or brines. Lakes hold a small percentage of the available water. Liquid fresh water is a small fraction of the water in the world, amounting to just 0.63 percent (Table 3). Of that fresh water, only a small fraction is readily accessible in lakes, rivers and streams (Table 4). In the future, deep drilling for fresh water supplies may be undertaken in the same way that it is now pursued for oil. Turning the more abundant salt and brackish water into a fresh water form suitable for agriculture and human consumption is becoming a more urgent task.

Table 3. Distribution of global water resources.

Source	Percent
Oceans and inland seas.	97.20
Icecaps and glaciers.	2.15
Liquid fresh water.	0.63
Atmospheric vapor.	0.001

Table 4. Distribution of fresh water resources.

Source	Volume [miles ³]
Ground water more than ½ mile deep.	1.00×10^6
Ground water less than ½ mile deep.	1.00×10^6
Lakes.	30,000
In surface soil and percolating downward.	16,000
Rivers and streams	300

WATER QUALITY

Drinking water contains small amounts of some contaminants, which do not necessarily pose a health risk. Some people can be more vulnerable to these contaminants than the general population. These include infants, some elderly, and immune-compromised persons undergoing cancer therapy, organ transplants, or suffering from HIV/AIDS and other immune system problems.

As water seeps through the ground it can leach naturally-occurring minerals, radioactive isotopes and substances resulting from animal husbandry or human activity. Some contaminants are:

1. Radioactivity

These can be naturally occurring or may result from oil and gas production and mining activities. The most prominent radioactive contaminant is the isotope radon²²² from the radioactive decay chain of U²³⁸. At room temperature, radon is emitted as a gas, then decays into solid products such as Pb²¹⁰ and Po²¹⁰ which could get embedded into the lung's alveoli creating a lung cancer hazard.

There is currently no Federal limit on radon concentration in drinking water, with a proposed limit from the USA Environmental Protection Agency (EPA). Measurements of typical aquifer water in Champaign County, Illinois in 2004 yield finished water levels activity in the range of 0-100 picocuries / liter (pCi/L), with an average of 100 pCi/L.

2. Microbial Contaminants

These include viruses and bacteria originating from sewage treatment plants, septic systems, agricultural livestock operations or wild life. A hazard exists from Cryptosporidium which is a protozoan found in untreated surface waters throughout the USA. The most commonly used filtration methods cannot guarantee its complete removal. Its ingestion may cause the cryptosporidiosis abdominal infection whose symptoms include nausea, diarrhea, and abdominal cramps. Healthy individuals can overcome the disease within a few weeks. People with weakened immune systems run the risk of developing a life threatening disease.

3. Inorganic Contaminants

These include salts and metals which could be naturally occurring or may result from urban storm water runoff, industrial or domestic waste water discharges, gas and oil production, mining or farming operations.

4. Organic Chemical Contaminants

These include synthetic and volatile organic chemicals as byproducts of industrial processes and petroleum production. They could also originate from gas stations leaking tanks, urban storm water runoff and septic systems.

5. Pesticides and Herbicides

These can originate from point or distributed sources from agriculture, storm water runoff and residential use on lawns and gardens and from golf courses.

Contamination is measured in terms of Maximum Contaminant Level (MCL) set by the Environmental Protection Agency (EPA), which is the highest level of contaminant that is allowed in drinking water. These are set as close to the Maximum Contaminant Level Goal (MCLG) which is the level of a contaminant in drinking water, allowing for a margin of safety, below which there is no known or expected risk to health.

The Action Level (AL) is the concentration of a contaminant that, if exceeded triggers treatment or other requirements that a water system must abide with. There exists no state or federal MCL for sodium, even though monitoring is required to provide information to consumers and health officials due to dietary precautions related to the relation between sodium intake and hypertension.

Table 5. Regulatory levels of water contaminants.

Substance (Units)	Maximum Contaminant Level Goal MCLG	Maximum Contaminant Level MCL	Typical Source
Regulated Substances in water leaving treatment facility			
Arsenic (ppb)	0	10	Erosion of natural deposits, runoff from orchards, runoff from glass and electronics production wastes.
Barium (ppm)	2	2	Discharge of well drilling waste, discharge from metal refineries, erosion of natural deposits.
Beta/Photon emitters activity density(pCi/L)	0	50	Decay of natural and man-made deposits.
Effective dose rate(millirem/year)	4		
Fluoride (ppm)	4	4	Water additive promoting healthy teeth. Illinois Department of Public Health optimal recommended level: 0.9-1.2 mg/L.
Compounds detected in the distribution system			

Total trihalomethanes (TTHMs) (ppb)	n/a	80	By product of drinking water chlorination.
Haloacetic acids (HAAs) (ppb)	n/a	60	By product of drinking water chlorination.
Chlorine and Chloramines (ppm)	4	4	Water disinfecting agents used to control microbes. Excessive levels can cause eye and nose irritation.

Bacteria in the distribution system and treatment facility			
Total Coliforms (% pos/month)	0 %	< 5 %	Naturally present in the environment.
Lead and Copper at customer taps			
Copper (ppm)	1.3	1.3	Corrosion of household plumbing, erosion of natural deposits, leaching from wood preservatives. Lead and Copper Rule (LCR) action level: 1,300 ppm.
Lead (ppb)	15	15	Corrosion of household plumbing, erosion of natural deposits. Lead and Copper Rule (LCR) action level: 15 ppb.
State regulated substances			
Sodium (ppm)	n/a	n/a	Erosion of naturally occurring deposits. Byproduct of home water softening.
Unregulated substances			
Chloroform (ppb)	n/a	n/a	Byproduct of drinking water chlorination.
Dichloroacetic Acid (ppb)	n/a	n/a	Byproduct of drinking water chlorination.

ppb = part per billion, 10^{-9}

ppm = part per million, 10^{-6}

NUCLEAR DESALINATION

According to the UN estimates, the number of people without access to safe drinking water is 1.1 billion, or nearly one in six persons worldwide. A solution is to draw water from the oceans and desalt it into fresh water. Being a negative entropy process, it requires the expenditure of some form of energy.

As far back as 1963 at Oak Ridge National Laboratory (ORNL) in the USA, Philip Hammond promoted the idea that fresh water can be obtained cheaply by desalting sea water using excess heat from large nuclear power plants. ORNL Director Alvin Weinberg, then a member of President John F. Kennedy's Science Advisory Committee, described this method of providing energy and making the desert bloom to the Atomic Energy Commission and Interior Department officials.



Figure 21. Nuplex Island consisting of nuclear power plants supplying fresh water and electricity for an Agro Industrial complex. Source: ORNL.

Hammond's concept was presented at a 1964 United Nations Conference on the Peaceful Uses of Atomic Energy in Geneva, Switzerland. It was supported by President Johnson's 1965 Water for Peace program, and was endorsed by the International Atomic Energy Agency (IAEA) in Vienna, Austria.

The ORNL Hammond team improved distillation technology, developed enhanced heat transfer surfaces and processes for multi stage flash distillation and designed aluminum vertical tube evaporators that were four times more efficient than contemporary models.

Another team lead by Kurt Kraus increased the efficiency of Reverse Osmosis (RO) and adapted it to desalination. In RO, pure water is produced by forcing salt bearing water through a semi permeable membrane that prevents salt passage. RO is used in almost half of today's desalination plants. The heat source for desalination is oil or gas, except for a new plant in Kalpakkam, India, which is coupled to a pair of existing nuclear reactors. At least three other nations have desalination reactors on the drawing board, suggesting that nuclear desalination may become a major fresh water source in the future.

BN-350 SODIUM COOLED FAST REACTOR DESALINATION PLANT

The BN-350 sodium cooled fast reactor was situated near the city of Aktau formerly Shevchenko on the Caspian Sea in Kazakhstan, and was placed in operation in 1972. BN-350 was designed for the dual purpose of producing electricity (150 MWe) and desalting water (120,000 m³ fresh water/day), which corresponds to a total power generation of 350 MWth.

The pioneering system was built as a pilot plan to prove that a commercial size fast reactor could be constructed for electricity and fresh water production. Experience has shown that the operation and maintenance costs in terms of reliability, availability, and capacity factor of power generation for the BN-350 plant were economically competitive with traditional fossil fuel or light water reactor power plants. However, the capital cost was high for this demonstration plant. The BN-350 reactor system has also been utilized for a wide range of experimental work supporting fast reactor development; and several design improvements were developed for the next generation BN-600 design.



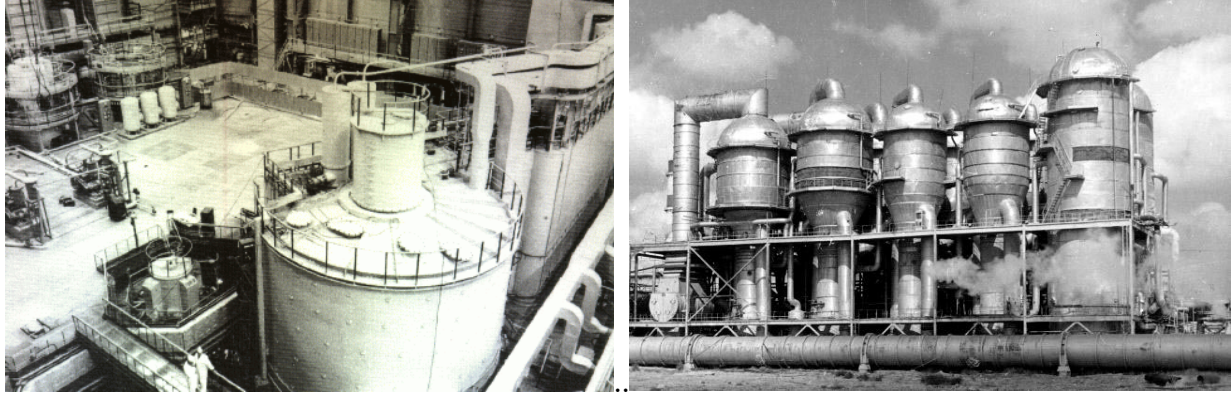


Figure 22. Dual purpose BN-350 sodium cooled fast reactor for electrical and fresh water production. Reactor hall and desalination units.

In June 1994, the reactor was shut down because of a lack of funds to buy fuel after the separation of Kazakhstan from the Soviet Union. In addition, the operating license of BN-350 had expired. It was reported that Russia's Ministry of Atomic Energy (MINATOM) proposed a joint project to the Kazakhstan Atomic Energy Agency for extending operation of the BN-350 by up to 10 years, then decommissioning it and providing replacement power. The Kazakhstan State Corporation for Atomic Energy instead planned to build a new 135 MWe fast reactor to replace the BN-350.

The BN-350 reactor plant is an outdated loop design, where the reactor is located in a separate vessel, and piping connects the reactor vessel with all other major system components, such as coolant pumps, and the intermediate heat exchangers. At one point it suffered a sodium water fire accident. Modern designs of fast reactors favor the pool design rather than the loop design, offering enhanced safety features, so it is doubtful that it will be brought back online, and it should be decommissioned.

DUAL PURPOSE NUCLEAR POWER PLANTS

The VK-300 boiling water reactor design is intended for dual electricity and heat generation. Different desalination technologies were considered for coupling to it including distillation systems: Multi Stage Flash (MSF), Multiple Effect Distillation (MED) and Vapor Compression (VC) with different patterns of thermal energy transfer from the reactor to the desalination units can be considered. Reverse Osmosis (RO) with initial water preheating or with purely electrical interconnection between the nuclear and desalination units as well as hybrid patterns are feasible, for instance: MED+RO and MSF+RO. The MED based distillation desalination units with horizontal tube film evaporators have accumulated operational experience and are reported as more economical than evaporators of other types, by a factor of 1.5-2.0 in terms of the energy consumption and by a factor of 1.5-1.8 in terms of the specific quantity of metal used.

The boiling water VK-300 reactor has a single circuit arrangement. The unit is equipped with a cogeneration turbine unit that includes controlled steam extraction ensuring heat supply to the process heat consumer via the intermediate circuit. The extraction parameters, including the pressure of 0.4 MPa and the steam flow rate to the intermediate circuit low pressure boiler of 400

t/h ensure a thermal load of 200 Gcal/h. An increase in the thermal load of up to the limiting value of 400 Gcal/hr is provided by the high pressure boiler to which steam is delivered from the uncontrolled extraction. The reduced live steam supply to the high pressure boiler is also possible from the main pipe downstream of the turbine stop and control valve. The steam pressure in the high pressure boiler is no more than 0.95 MPa. The water pressure in the intermediate circuit at 1.2 MPa exceeds the heating steam pressure in the boilers, which prevents the penetration of radioactive contaminants to the intermediate circuit water.

It is proposed to use resource saving finned tube heat exchangers as heat exchanging equipment for the heat transfer from the primary circuit to the intermediate circuit and from the intermediate circuit to the distillation unit circuit. The same heat exchangers can be used as part of the auxiliary heat exchanging equipment. In terms of their thermodynamic parameters, these heat exchangers are comparable to the most known effective equipment such as plate type finned heat exchangers.

Figure 23 shows a standard VK-300 reactor of Russian design coupled to an Multiple Effect Distillation, MED unit. To generate heating steam for the first stage of the multi stage evaporator unit, an evaporating flash chamber is used in which the intermediate circuit water boils up due to flash evaporation.

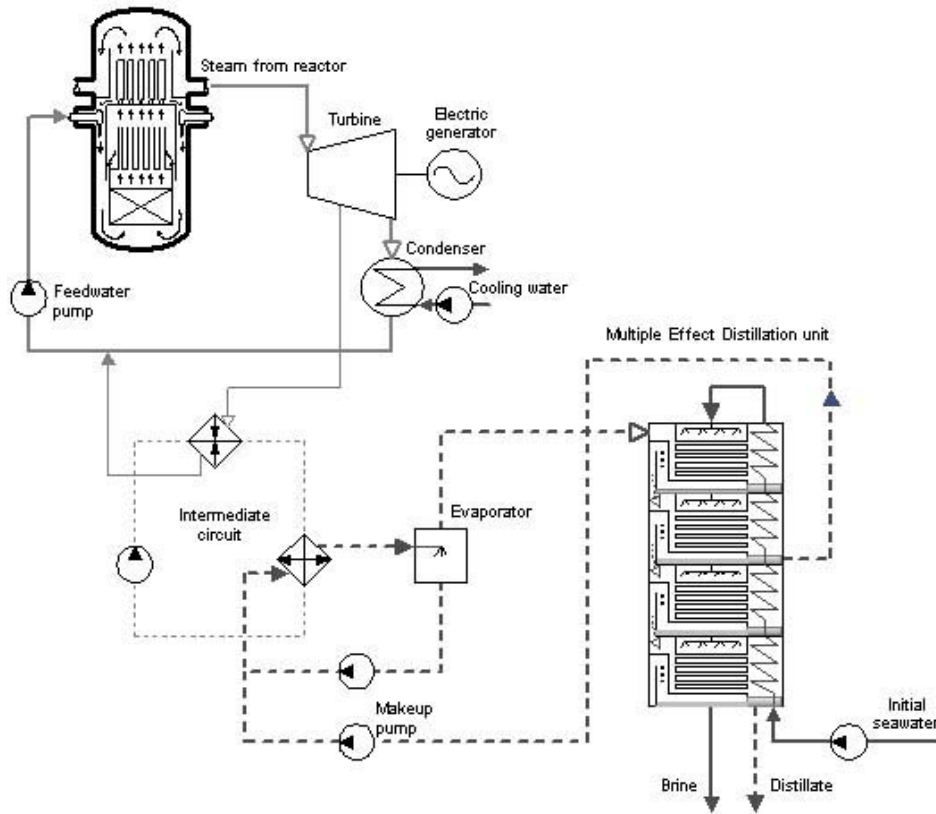


Figure 23. Boiling water reactor VK-300 unit coupled to a back-pressure turbine and a Multiple Effect Distillation (MED) desalination unit.

One VK-300 power unit is capable of providing with thermal energy a distillation complex with a total capacity of 300,000 m³/day. If less strict requirements are made on the fresh water quality, membrane technology and RO can be used in conjunction with the MED facility.

KALPAKKAM, INDIA PILOT NUCLEAR DESALINATION PLANT

India is among the most water stressed countries with a deficit of 25 percent and by the year 2025, is projected to be among the water scarce countries with a water availability 1340 m³/(person.year) with a deficit of 33 percent. This is an average figure, but for a large fraction of the Indian population, water scarcity is already a reality. To ensure a secure future, efforts to improve water availability are pursued by integrated water resource management, which includes an array of measures:

1. Conservation of water.
2. Rain water harvesting.
3. Water recovery and recycle.
4. Removal of contaminants.
5. Augmentation of water availability with large size desalination plants.

An ongoing project at Kalpakkam, India involves the coupling of the 170 MWe Pressurized Heavy Water Reactor (PHWR) to a Multi Stage Flash and Reverse Osmosis desalination unit producing 6,300 m³/day of fresh water. Designated as the Nuclear Desalination Demonstration Project (NDDP) it aims at demonstrating the safe and economic production of fresh water by nuclear desalination of seawater and comprises a 4,500 m³/d Multi Stage Flash (MSF) and an 1,800 m³/d Reverse Osmosis (RO) plant.

The MSF plant uses low pressure steam from the Madras Atomic Power Station (MAPS) units 1 and 2 at Kalpakkam. The objectives of the NDDP project at Kalpakkam are as follows:

1. To establish the indigenous capability for the design, manufacture, installation and operation of nuclear desalination plants.
2. Demonstrate the safe and economic production of water.
3. Generate necessary design inputs and optimum process parameters for large size nuclear desalination plant (10 MGD).

The hybrid desalination plant is envisaged to possess a number of advantages:

1. A part of high purity desalted water produced from MSF plant will be used for the makeup demineralized water requirement after necessary treatment for the power station.
2. Blending of the product water from RO and MSF plants would provide the requisite quality drinking water.
3. The RO plant can continue to be operated using off site power to provide the water for drinking purposes during the shutdown of the power station.



Figure 24. Kalpakkam pilot plant for dual purpose nuclear electricity and fresh water production.

The 6,300 m³/d combined MSF and RO nuclear desalination project is located between MAPS and the PFBR at Kalpakkam. The MSF plant uses the required amount of Low Pressure (LP) steam for seawater desalination. To avoid any chance of ingress of radioactivity as tritium to the MSF process and product water, an isolation heat exchanger between MAPS steam supply and the brine heater of MSF has been incorporated. The LP steam is tapped from the manholes in the cold reheat lines after the High Pressure (HP) turbine exhaust from both the nuclear reactors (MAPS 1 and 2). The moisture content is removed through a moisture separator. The steam is sent to an intermediate isolation heat exchanger to produce process steam for brine heater of the MSF plant. It is designed to keep the steam temperature in a brine heater below 130 °C to avoid scaling on the tube side. The condensate from the isolation heat exchanger is returned back to the deaerator section of the power station. Adequate provisions for monitoring and control have been incorporated for isolation of the steam supply in case of shutdown of the power station or desalination plant.

The NDDP requires around 2,000 m³/hr of seawater. After detailed study, it was decided to use process cooling water from the MAPS outfall as a source of seawater supply for the NDDP.

DESALINATION METHODS

Desalination, Desalinization, or Desalting is a process that removes dissolved minerals, including but not limited to salt (NaCl) from seawater, brackish water, or treated wastewater. A number of technologies have been developed for desalination, including distillation, reverse osmosis (RO), electrodialysis, and vacuum freezing. Some of the desalination methods are described.

DISTILLATION METHODS

In the distillation process, feedwater is heated, evaporated then condensed to separate out the dissolved minerals. The most common methods of distillation include Multi Stage Flash (MSF), Multiple Effect Distillation (MED), and Vapor Compression (VC). Some distillation plants are a hybrid of more than one desalination technology. The waste product from these processes is a brine solution with high salt concentration.

MULTI STAGE FLASH, MSF EVAPORATION

In MSF, the feedwater is heated and the pressure is lowered in cascading successive stages. The water would exist at lower than its saturation pressure, flashing into steam. This process constitutes one stage of a number of stages in series, each of which is at a lower pressure.

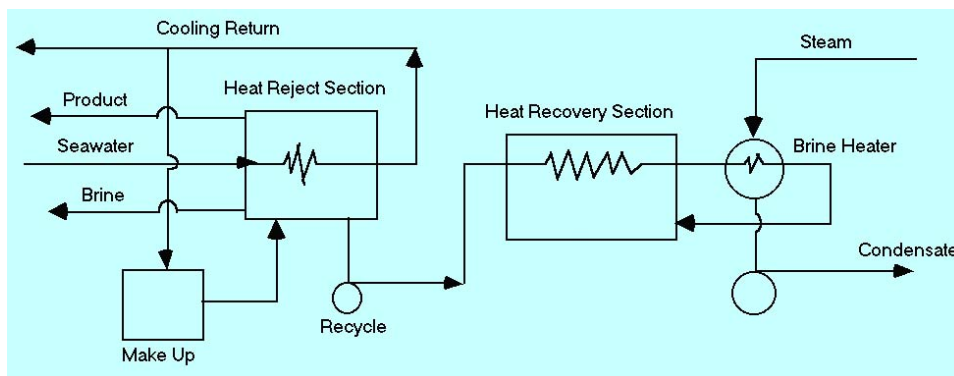
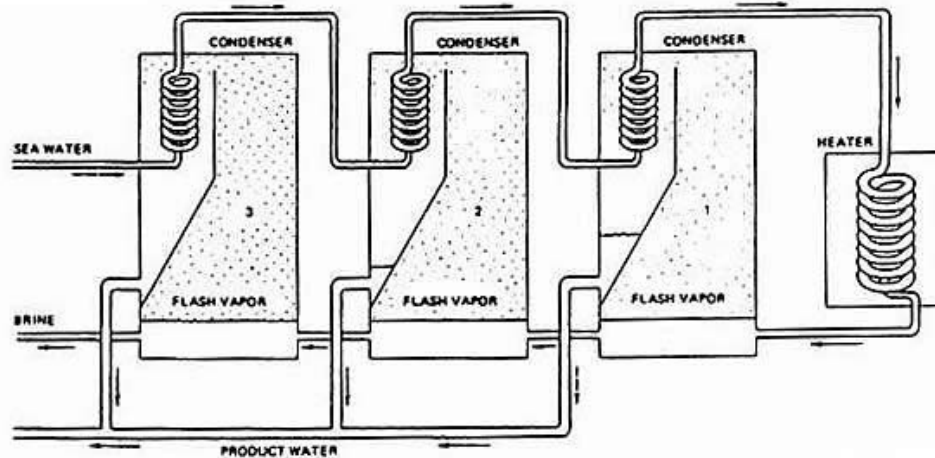


Figure 25. Multi Stage Flash, MSF evaporation with recycle flow diagram.

VAPOR REHEAT FLASH DISTILLATION

This system uses direct contact heat exchangers. It is similar to the MSF process, except that the fresh water is recycled and used to condense more vapor. Heat is recovered from the recycled fresh water either by liquid to liquid heat exchange or by metallic heat exchangers. Larger volumes are to be handled in this approach increasing complexity and cost.

MULTIPLE EFFECT DISTILLATION, MED

In the Multiple Effect Distillation, MED process, the feedwater passes through a number of evaporators in series. Vapor from one series is subsequently used to evaporate water in the next series.

Multi-Effect Distillation (MED), like MSF, is most feasible when located next to an electrical generation facility. Although the initial investment is usually higher for MED than MSF, operation of MED facilities is generally easier and more economical. MED, like MSF, uses a

progression of stages with decreasing pressures. Some of the feedwater is flash evaporated, but most of the seawater is dispersed over an evaporator tube bundle and boiled and evaporated there. Steam then condenses in the effect to produce fresh water.

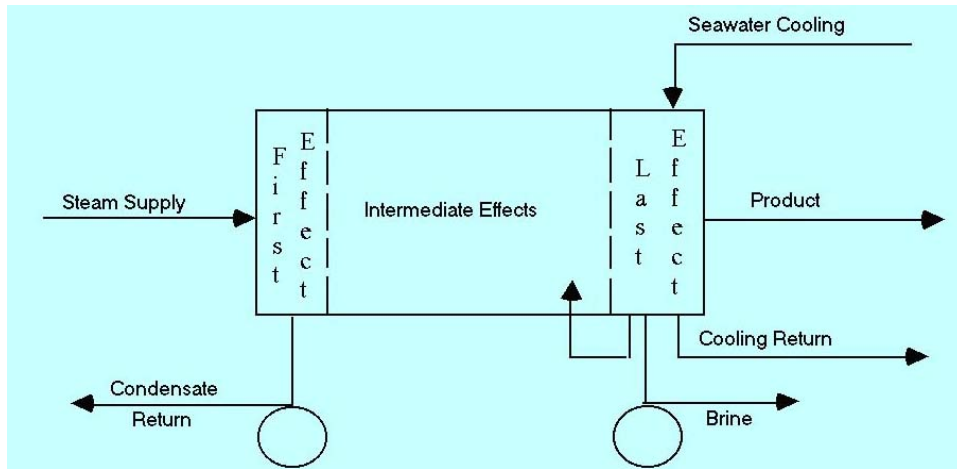


Figure 26. Multiple Effect Distillation, MED.

VAPOR COMPRESSION, VC

The VC process involves evaporating the feedwater, compressing the vapor, then using the heated compressed vapor as a heat source to evaporate additional feed-water.

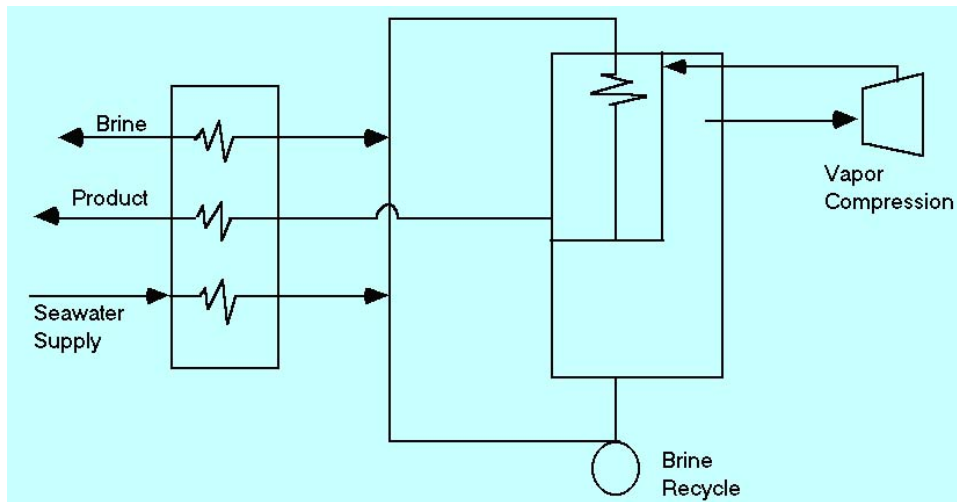


Figure 27. Vapor Compression, VP desalination.

MEMBRANE METHODS

REVERSE OSMOSIS, RO

In Reverse Osmosis, RO feedwater is pumped at high pressure through permeable membranes, separating salts from the water. The feedwater is pretreated to remove particles that would clog the membranes. The quality of the water produced depends on the pressure, the concentration of salts in the feedwater, and the salt permeation constant of the membranes. Product water quality can be improved by adding a second pass of membranes, whereby product water from the first pass is fed to the second pass.

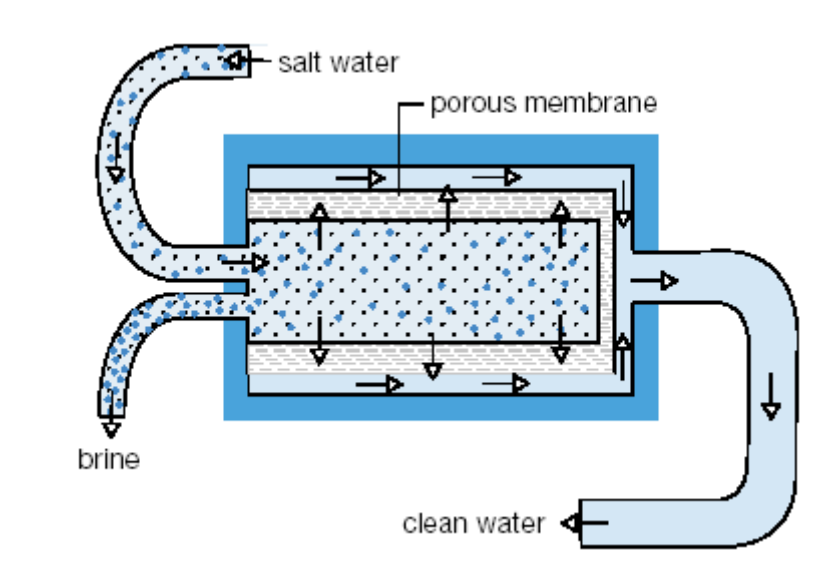


Figure 28. Reverse Osmosis principle of operation.

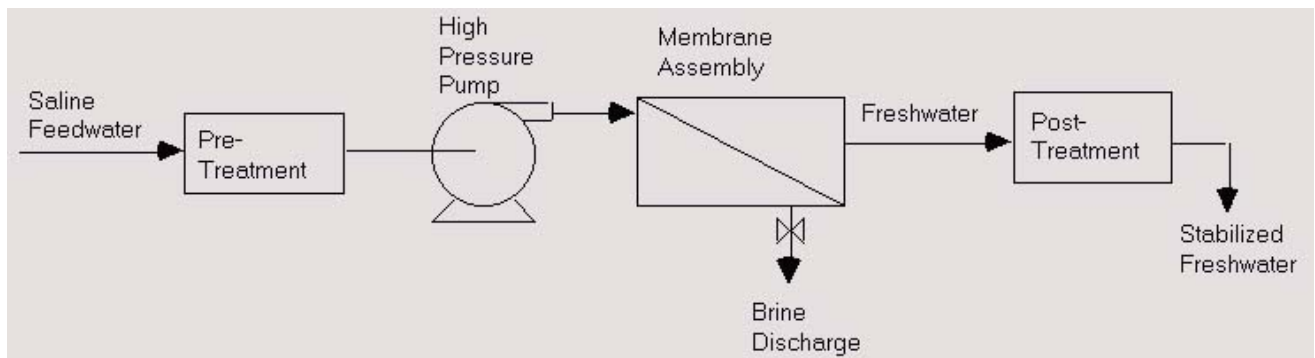


Figure 29. Reverse Osmosis, RO desalination plant process.

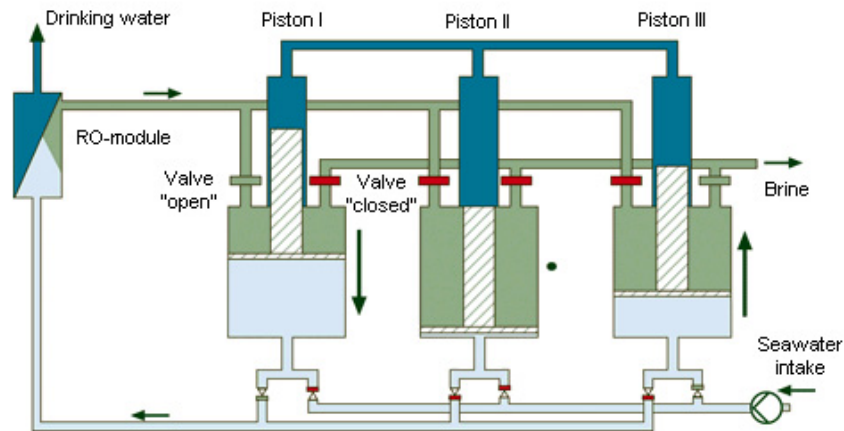


Figure 30. Configuration of pumping in the Reverse Osmosis (RO) process. Source: Enercon.

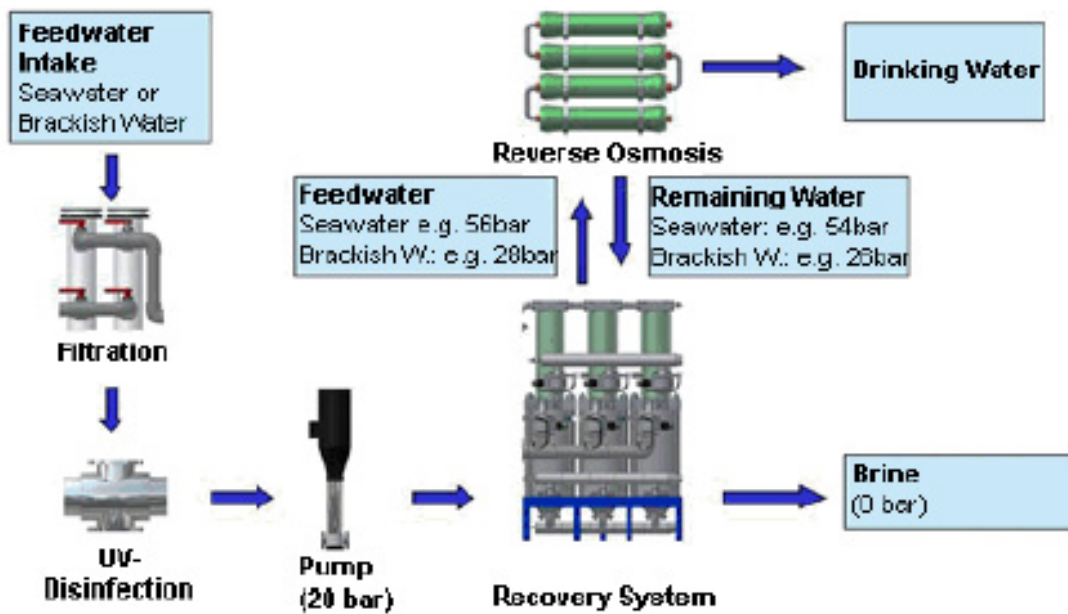


Figure 31. Filtration, disinfection and energy recovery for the production of potable water. Source: Enercon.

ELECTRO-DIALYSIS

In Electro-Dialysis (ED) desalination, a direct electrical current (DC) is run through brackish water. Dissolved salts and minerals are thereby separated into positive and negative ions that strain through one of two semi-permeable membranes that allow only the positive or negative ions to pass through and prevent water from filtering through.

Electro Dialysis is an electrochemical separation process applied to an aqueous solution in which organic and inorganic substances are dissolved and are dissociated in electrical positive and negative ions through the process of hydrolysis. The basic electrical property of such a solution is to be an electricity conductor.

If two electrodes of opposite polarity are introduced in such a solution, it is possible to cause the migration of the negative ions towards the positive electrode and the positive ions to the negative electrode. To avoid the mixing of the separated ions, some permselective monovalent membranes are located between the electrodes. Such thin membranes, made of appropriate plastic material, are provided with micro channels having fixed chemical electrical charges inside, which can be negative (cationic), or positive (anionic).

The cationic membrane does not allow the negative ions migration, and the anionic membrane does not allow the positive ions migration. When several anionic and positive permselective membranes are alternatively arranged and properly spaced in the solution, it is possible to create small chambers or cells in which the ions of the substances can be separated and collected in concentrated or diluted form.

It is possible by this selected ionic migration, to extract from other undesired components of the solution, an ionized substance in purified form. The simple separation of an inorganic salt such as NaCl from a solution for fresh water production is shown in Fig. 29.

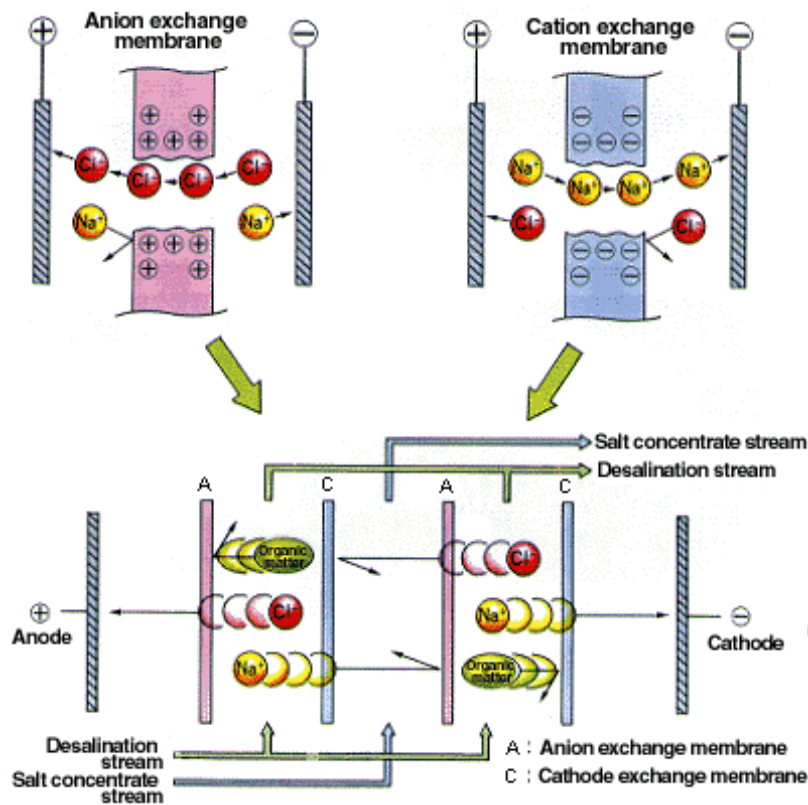


Figure 32. Principle of operation of the electro dialysis process.

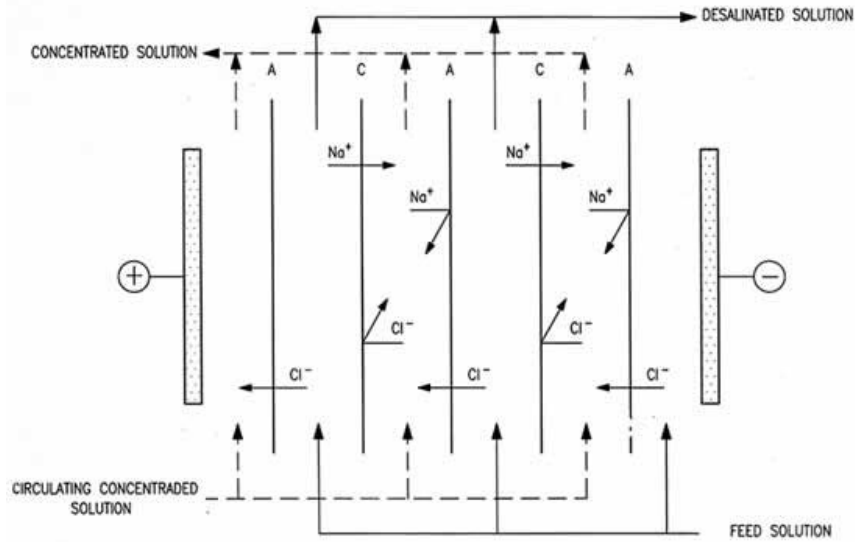


Figure 33. Electro-Dialysis process for NaCl water purification.

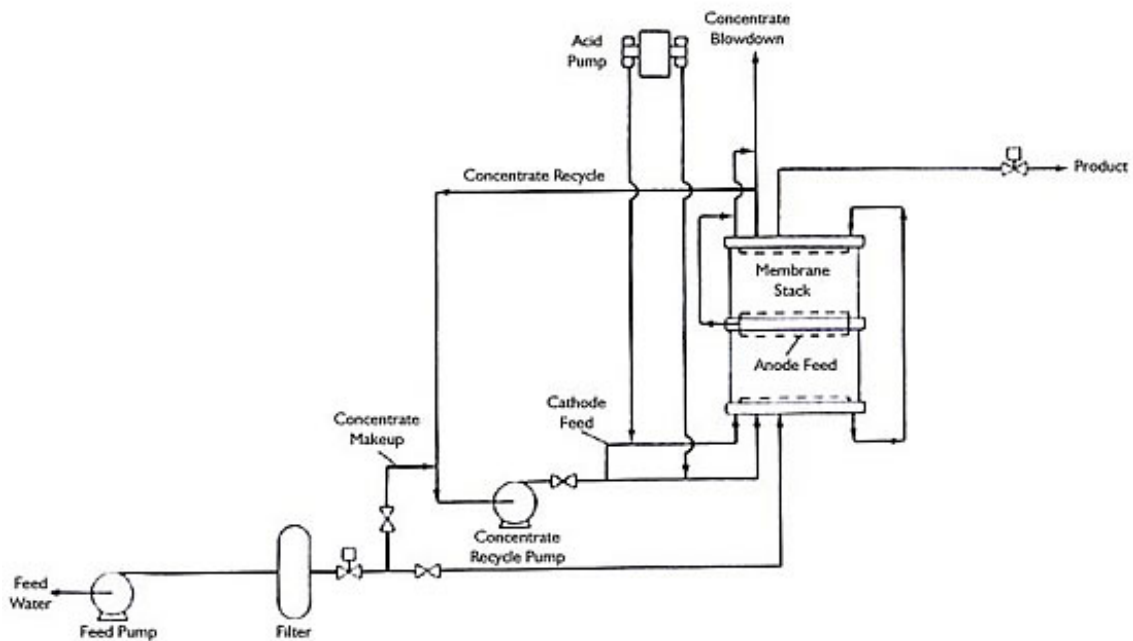


Figure 34. Layout of an electro-dialysis plant.

POROUS HYDROPHOBIC MEMBRANE DISTILLATION

Membrane distillation uses a special membrane to bring out the water vapor generated from collected seawater, collecting it as freshwater, and it is a revolutionary new method different from its predecessors. This special membrane is a porous hydrophobic membrane, which means that water vapor can pass through it, but drops of water cannot. By passing hot seawater through one

side of the membrane, only the water vapor generated from the seawater passes through. The water vapor is then cooled by the cool water on the other side of the membrane, forming water droplets, resulting in freshwater.

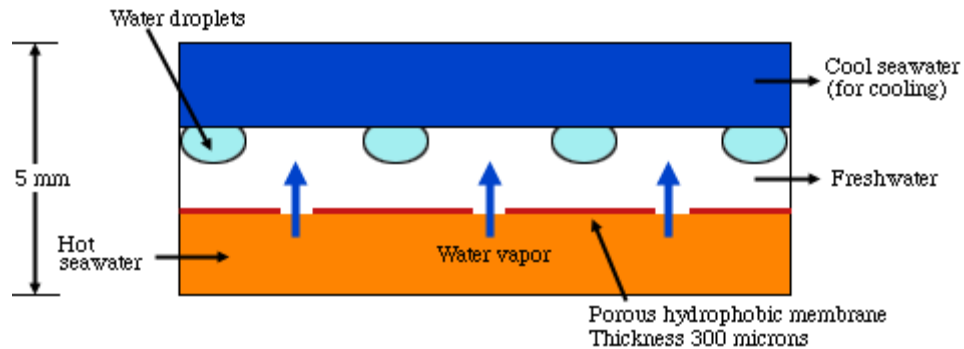


Figure 35. Hydrophobic Membrane Distillation operation and module developed by Takenaka, Japan.

Units for the membrane distillation are simple with no replaceable parts, enabling the system to be maintenance free. Units can be used with fluctuating heat sources of relatively low temperatures (50-60 °C), so water creation is possible using waste

AQUAPORIN AQP1 WATER CHANNELS POLY-PEPTIDE PROTEIN MEMBRANE

The 2003 Nobel Prize was awarded in part to Peter Agre of Johns Hopkins University for his discovery, around 1990, of a membrane protein that allows water to pass through cell walls.

The Danish company Aquaporin has developed an approach to desalt seawater that replaces the polymer-layering of traditional industrial films by biological membranes.

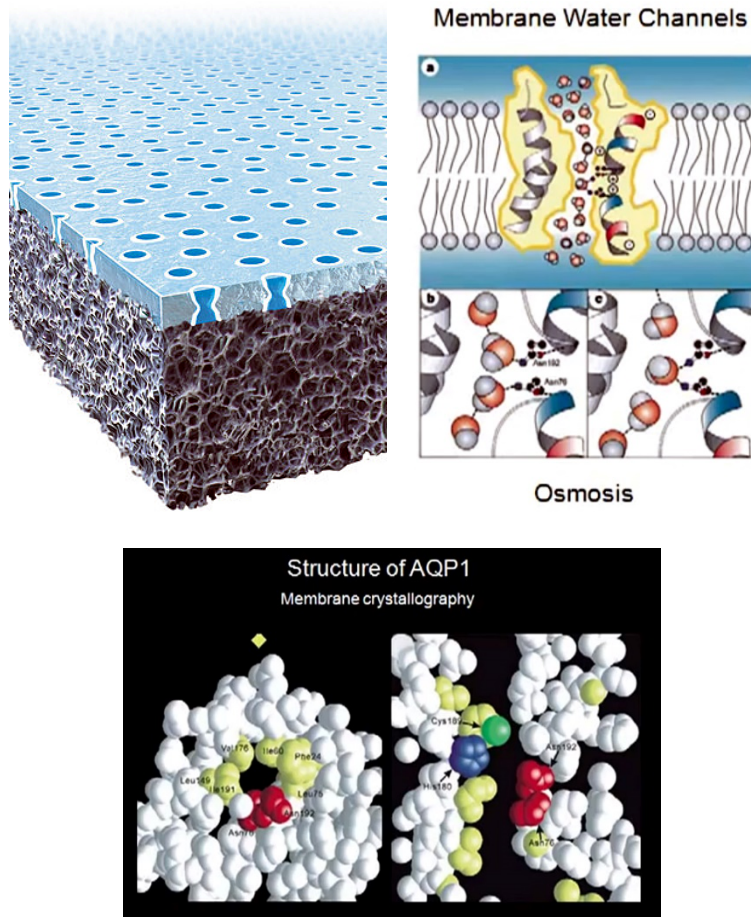


Figure 36. Aquaporin AQP1 protein membrane. Source: Aquaporin.

GRAPHENE OXIDE MEMBRANE

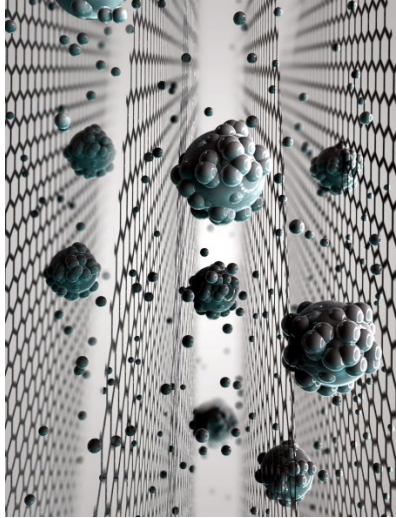


Figure 37. Graphene membrane schematic. Source: University of Manchester [16].

Graphene was characterized at the University of Manchester, UK in 2004. It comprises a single layer of carbon atoms arranged in a hexagonal lattice. It possesses extraordinary tensile strength and electrical conductivity. It has been difficult to produce large quantities of single-layer graphene using existing methods, such as Chemical Vapor Deposition (CVD) [16].

However, graphene oxide can be produced by simple oxidation in the lab as an ink or a solution then spread on a substrate or porous material and be used as a membrane offering a potential advantage over single-layered graphene [16].

Its use in clean water production remains an issue. To make single-layer graphene permeable, one needs to drill small holes in the membrane. If the hole size is larger than one nanometer, the salts go through that hole. A membrane with a very uniform less than one nanometer make it useful for desalination.

Graphene oxide membranes have been used in sieving out small nanoparticles, organic molecules and even large salts. To filter out common salts, requires even smaller sieves. Graphene oxide membranes become swollen when immersed in water, allowing smaller salts to flow through the pores along with the water molecules. Placing walls made of epoxy resin used in coatings and glues on either side of the graphene oxide membrane is sufficient to stop the expansion. Restricting the swelling allowed the tuning of the properties of the membrane. When common salts are dissolved in water, they form a shell of water molecules around the salt molecules, allowing the capillaries of the graphene-oxide membranes to block the salt from flowing through along with the water. The size of the shell of water around the salt is larger than the channel size, so it cannot go through. The water molecules flow through the membrane barrier, making it ideal for use in desalination. When the capillary size is around one nanometer, which is very close to the size of the water molecule, those molecules form a nice interconnected arrangement like a train that makes the movement of water faster: if you push harder on one side, the molecules all move on the other side because of the hydrogen bonds between them [16].

Graphene oxide membranes need to be inexpensively produced at an industrial scales their durability under prolonged contact with seawater must be demonstrated. The membrane must be resistant to fouling by salts and biological material, which requires existing polymer barriers to be

periodically cleaned or replaced. The goal is to create a filtration device that will produce potable water from seawater, brines or wastewater with a minimal energy input [16].

REFRIGERATION METHODS

VACUUM FREEZE SEPARATION

Like distillation, freezing emulates nature where it is observed that icebergs are primarily fresh water, yet they float on the oceans surface because of their lower density than salt water. In fact, it takes less energy to freeze sea water than to evaporate it, which makes such a technique attractive. Other advantages include minimized corrosion and scale formation problems, and the ability to use conventional tubular and plate heat exchangers.

In the vacuum freezing process, cooled saline water is sprayed into a vacuum chamber at an absolute pressure of 3 mm of mercury. Part of the water adiabatically flashes into vapor removing heat from the remainder. Since it is already close to its freezing point, ice crystals form. There results a slurry of ice and brine which is taken to a washer and melter where the ice particles yield fresh water.

The difficulty with it is the tenacity of the brine film that adheres to the crystals of pure water and must be removed by washing with fresh water in a hydraulic wash column. There, the hydraulic pressure drop between the inlet and the brine removal screens forces a piston of ice up a column. The part of ice above the brine level is washed with some fresh water and scraped mechanically and the ice melted.

SECONDARY REFRIGERANT METHOD

A liquid hydrocarbon refrigerant that does not mix with water such as butane, is vaporized in direct contact with saline water by heat transfer from the water to the butane. The cooling of the pre cooled feed water causes ice crystals to form. These are washed to remove the brine and then melted into fresh water.

Compressed butane vapor is passed from the crystallizer to the melter through a compressor. It condenses back into liquid form for re use within the cycle. Care must be taken to strip the product water from traces of butane to avoid taste and explosion problems.

OTHER DESALINATION METHODS

ION EXCHANGE METHOD

This method can be used for the treatment of brackish water with up to 3,000 ppm of dissolved solids. Salts are removed with cation and anion exchange resins. The exhausted resins are regenerated with acids, ammonia or lime, depending upon which resin is used. A thermal regeneration system can also be used.

HYDRATE PROCESS

Saline water is mixed with a hydrate forming gas such as propane to form insoluble crystals of a solid hydrate. The slurry of crystals and brine is transferred to a wash column and then the

washed crystals are moved to a decomposition chamber. Temperature and pressure changes induced by the compressed gas from the first chamber are used to decompose the hydrate.

RAPID SPRAY DISTILLATION, RSD

The water could be ejected through a nozzle creating a mist of droplets at the microns in diameter level. The surface area of the droplets becomes substantial. This enhances the adiabatic evaporation of the water from the large surface area. The evaporated water is condensed into fresh water. What is left behind is a brine easily converted to salt in dry form. Since water is not boiled in a large container maintained under vacuum like in the distillation processes, the capital cost would be substantially reduced. This process can be used to remove pollutants such as arsenic and other dissolved substances from otherwise unusable water.

CLOUD FORMATION DISTILLATION, CFD

We here propose this new approach using the properties of charged droplets as occurs in nature in cloud formations. It occurs in the condensation trails or “contrails” of high flying airplanes. This method would use the same concept used in the cloud chamber particle detection process and applies it for water desalination.

If air is saturated with water vapor and ionized by some agency such as x-rays, gamma radiation from a radioisotope, or ultraviolet light, then suddenly expanded, the air is adiabatically cooled below its saturation temperature and the water vapor condenses on the ions in the air. If the ionized air were contained between the plates of a condenser with the plates connected to a direct current (DC) source, such as wind turbines, the ensuing electric field would divert the ions carrying the fresh water to be condensed on the condenser plates. If the condenser plates are horizontal, gravity will help the electric field move the fresh water droplets to the condenser plate. Magneto-hydrodynamics configurations could use a magnetic field to move the charged ions carrying the fresh water in a direction perpendicular to the magnetic field to be collected on some cooled collection plates.

COMPARISON OF DISTILLATION AND REVERSE OSMOSIS

One advantage of distillation plants is that there is a greater potential for economies of scale. Distillation plants also do not shut down a portion of their operations for cleaning or replacement of equipment as often as RO plants, although distillation plants can and have shut down for tube bundle replacement and cleaning. Pretreatment requirements are greater for RO plants, because coagulants are needed to settle out particles before water passes through the membranes. Unlike RO plants, distillation plants do not generate waste from the backwash of pretreatment filters.

Advantages of RO plants over distillation include:

1. Plant feedwater generally does not require heating, so the thermal impacts of discharges are lower.
2. Fewer problems with corrosion.
3. Lower energy requirements.
4. Higher recovery rates of about 45 percent for seawater.

5. Can remove unwanted contaminants, such as trihalomethane precursors, pesticides, and bacteria.
6. Plants take up less surface area than distillation plants for the same amount of water production.

ENERGY USAGE

The energy used in the desalination process is primarily electricity and heat. Energy requirements for desalination plants depend on the salinity and temperature of the feedwater, the quality of the water produced, and the desalting technology used. Estimates for electricity use requirements for various technologies for seawater desalination are shown in Table 6.

Table 6. Energy usage of different desalination technologies.

Desalination Technology	Energy usage [kW.hr/(acre.ft)]
Multi Stage Flash, MSF evaporation	3,500-7,000
Multiple Effect Distillation, MED	2,500-5,000
Vapor Compression, VC	10,000-15,000
Reverse Osmosis, RO	
Single pass	5,800-11,000
Double pass	6,500-12,000

1 acre = 43,560 sq ft.

1 acre.ft = 325,851 gallons.

In addition to electricity requirements, MSF, MED, and some VC plants also use thermal energy to heat the feedwater. Because of the inefficiency of converting thermal energy to electricity, there is a high energy penalty if electricity is used to heat the feedwater. For instance, in addition to the 3,500 to 7,000 kW.hr/acre.ft of energy required for electricity, the thermal energy needs for a MSF distillation plant is estimated at 270 million Btu/AF (about 26,000 kW.hr/acre.ft); for MED plants, the estimated additional thermal energy requirements are 230 million Btu/acre.ft (about 22,000 kW.hr/acre.ft). Consequently, the total energy needs for distillation technologies are higher than for RO technologies.

Energy use requirements for desalination plants are high. For example, an estimated 50 million kW.hr/yr would be required for full-time operation of the City of Santa Barbara's desalination plant to produce 7,500 acre.ft/yr of water. In contrast, the energy needed to pump 7,500 acre.ft/yr of water from the Colorado River Aqueduct or the State Water Project to the Metropolitan Water District (MWD) of Southern California is 15 to 26 million kW.hr/yr. These energy requirements may be compared to the energy use of a small to medium sized industrial facility such as a large refinery, small steel mill, or large computer center, which uses 75,000 to 100,000 kW.hr/yr.

THE DESALINATION PROCESS

INPUT FEEDWATER

Desalination plants may use seawater directly from the sea through offshore intakes and pipelines, or from wells located on the beach or seafloor, brackish groundwater, or reclaimed water as feed-water. Since brackish water has a lower salt concentration, the cost of desalting brackish water is generally less than the cost of desalting seawater. Intake pipes for desalination plants should be located away from sewage treatment plant outfalls to prevent intake of discharged effluent. If sewage treatment discharges or other types of pollutants are included in the intake, however, the pre- and post-treatment processes should remove the pollutants.

PRODUCT FRESH WATER

Distillation plants produce a high quality product water that ranges from 1.0 to 50 parts per million of total dissolved solids (ppm tds), while RO plants produce a product water that ranges from 10 to 500 ppm tds.

The recommended California drinking water standard for maximum tds is 500 mg/L, which is equivalent to 500 ppm. In desalination plants that produce water for domestic use, post treatment processes are often employed to ensure that the product water meets the health standards for drinking water as well as recommended aesthetic and anti-corrosive standards.

Desalination product water may be used in its pure form, for instance for make-up water in power plant boilers or it may be mixed with less pure water and used for drinking water, irrigation, or other uses. The desalinated product water is usually more pure than drinking water standards, so when product water is intended for municipal use, it may be mixed with water that contains higher levels of total dissolved solids. Pure desalination water is highly acidic and is thus corrosive to pipes, so it has to be mixed with other sources of water that are piped onsite or else adjusted for pH, hardness, and alkalinity before being piped offsite.

RECOVERY OF PRODUCT WATER

The product water recovery relative to input water flow is 15-50 percent for most seawater desalination plants. For every 100 gallons of seawater, 15 to 50 gallons of pure water would be produced along with brine water containing dissolved solids. A desalination plant's recovery varies, in part because the particulars of plant operations depend on site-specific conditions.

FEED WATER PRETREATMENT

Pretreatment processes are needed to remove substances that would interfere with the desalting process. Algae and bacteria can grow in both RO and distillation plants, so a biocide, usually less than 1 mg/L chlorine, is required to clean up the system. Some RO membranes cannot tolerate chlorine, so dechlorination techniques are required. Ozone or ultraviolet light may also be used to remove marine organisms. If ozone is used, it must be removed with chemicals before reaching the membranes. An RO technology has been developed that does not require chemical pretreatment.

In RO plants, suspended solids and other particles in the feed-water must be removed to reduce fouling of the membranes. Suspended solids are removed with coagulation and filtration. Metals in the feed-water are rejected along with the salts by the membranes and are discharged in the brine. With normal concentrations for metals in seawater, the metals present in the brine

discharge, though concentrated by the RO process, would not exceed discharge limits. Some distillation plants may also need to remove metals due to potential corrosion problems.

FILTER BACK WASHING, MEMBRANE CLEANING

The filters for pretreatment of feed-water at RO plants must be cleaned every few days or backwashed to clear accumulated sand and solids. The RO membranes must be cleaned approximately four times a year and must be replaced every three to five years. Alkaline cleaners are used to remove organic fouling, and acid cleaners are used to remove scale and other inorganic precipitates. All or a portion of RO plants must be shut down when the membranes are replaced. When RO plants are not used continuously, the RO membranes must be stored in a chemical disinfection/preservation solution that must be disposed of after use. Distillation plants can also be shut down for tube bundle replacement, which is analogous to membrane replacement.

SCALING PREVENTION AND REMOVAL

Desalination plant components must be cleaned to reduce scaling—a condition where salts deposit on plant surfaces, such as pipes, tubing or membranes. Scaling is caused by the high salt concentration of seawater and can result in reduced plant efficiency and corrosion of the pipes. In general, scaling increases as the temperature increases; thus scaling is of greater concern for distillation plants, since RO plants require lower temperatures to operate. Scaling can be reduced by introducing additives to inhibit crystal growth, reducing temperature and/or salt concentrations, removing scale-forming constituents, or seeding to form particles. Once scales have formed, they can be removed with chemical or mechanical means.

In addition to scaling, both RO and distillation plant intake and outfall structures and pipelines can become fouled with naturally occurring organisms or corroded. Structures and pipelines may be cleaned by mechanical means or by applying chemicals or heat. Feed-water may also be deaerated to reduce corrosion.

WASTE DISCHARGE

Desalination plants produce liquid wastes that may contain all or some of the following constituents: high salt concentrations, chemicals used during defouling of plant equipment and pretreatment, and toxic metals which are most likely to be present if the discharge water was in contact with metallic materials used in construction of the plant facilities. Liquid wastes may be discharged directly into the ocean, combined with other discharges such as power plant cooling water or sewage treatment plant effluent, before ocean discharge, discharged into a sewer for treatment in a sewage treatment plant, or dried out and disposed of in a landfill. Desalination plants also produce a small amount of solid waste: spent pretreatment filters and solid particles that are filtered out in the pretreatment process.

For example, the capacity of the City of Santa Barbara's desalination plant is 7,500 acre.ft/yr (about 7.16 MGD). In May 1992, the plant produced 6.7 MGD of product water and generated 8.2 MGD of waste brine with a salinity approximately 1.8 times that of seawater. An additional 1.7 MGD of brine was generated from filter backwash. Assuming that concentrations of suspended solids in the seawater feed range from 10 to 50 ppm, approximately 1.7 to 5.1 cubic yards per day of solids were generated, which is equivalent to one to two truck-loads per week.

EXTRACTION OF MINERAL PRODUCTS FROM SEAWATER

If the brine is fully evaporated numerous products from sea water can be extracted, or the primary NaCl salt could be used as table salt or for the production of chlorine and sodium. About 37 tons of high grade fertilizer can be produced from each million gallons of sea water that is pumped in a desalination plant anyway.

Even uranium and gold can be extracted from the pumped sea water. Recovery of uranium from sea water may even be cost competitive with the breeder reactor or fuel reprocessing. Since large amounts of sea water would be pumped to a desalination plant, coupling uranium recovery and other minerals to fresh water desalination may provide an economical synergy. Titanium oxide has been used as an adsorbent for uranium from seawater.

Production costs are around \$ 300-560 per pound of uranium. Still, extraction from seawater is still around five times dearer than mining uranium. By using seawater extraction, some of the environmental costs of obtaining uranium ore on land can be minimized. Unlike mining, there are no problems with producing contaminated wastewater, impacting the environment and causing health issues for miners.

At the Takazaki Radiation Chemistry Research Establishment of the Japan Atomic Energy Research Institute (JAERI), a uranium adsorbent generated by the irradiation processing of polymer fiber was tried. Adsorbents have been synthesized that have the functional amidoxime group that selectively adsorbs heavy metals. Uranium adsorption capacity of this polymer fiber adsorbent is high in comparison to the conventional titanium oxide adsorbent. The attainment of a 10-fold higher adsorption capacity on a dry adsorbent basis was shown. This adsorbent can make practical use of wave motion or tidal power for efficient contact with seawater. It has been used since 1996 in the actual marine environment by utilizing moored small-scale test equipment for recovery of trace metals including uranium from seawater. The mats are 50-100 yards long and are suspended 100-200 yards under the surface. As they are brought to the surface, they are rinsed using a mild acid solution that captures the uranium. The system can be repeated several times.

A recovery system based upon this adsorbent uses ocean current to produce efficient contact between the adsorbent and a large volume of seawater. The required quantity of adsorbent at the time of mooring is 40,000 tons, and the quantity exchanged due to adsorbent performance decline becomes 10,000 tons per year.

The adsorbent is used in the form of 15 cm wide strips of nonwoven sandwiching a spacer and coiled into a short cylindrical shape. This roll is loaded into a cage with an adsorption bed of a short cylindrical shape of 4 m diameter. A single adsorption bed is loaded with 125 kg of adsorbent. The quantity of adsorbed uranium per bed during 60 days is 750 g. These adsorption beds are strung and tied together by rope at roughly 0.5 m intervals to form a basic unit.

The adsorption bed is a stainless steel metal mesh cage that has specific a gravity of 7.8 and a mass of 685 kg. A 15 cm wide sheet of adsorbent at 150 g/m² is coiled so as to load 125 kg of adsorbent. A plastic mesh sheet is inserted between adsorbent windings as a spacer. The specific gravity is 1.15 so total mass is 104 kg. Total bed mass becomes 914 kg. The weight in seawater becomes 611 kg, so the weight when pulled up becomes 1,161 kg.

Although 40,000 tons of adsorbent must be produced beforehand prior to the start of uranium recovery, production then becomes 10,000 tons per year for replenishment during the time period of regular uranium recovery.

A trial calculation of the cost of manufacture of 10,000 tons per year of adsorbent was undertaken. Precursor material cost covers a large proportion in comparison to production equipment cost. Even if it is assumed an increase in production equipment for annual production of 40,000 tons per year, the equipment cost increase would be held down to slightly more than 2-fold. From such estimates, the production unit cost of adsorbent was estimated to be 493,000 yen / ton. The quantity of recovered uranium becomes 120 kg / ton of adsorbent for the case of 20 reuses. Therefore the adsorbent production cost required for recovery of 1 kg of seawater uranium is estimated to be 4,100 yen / kg-U.

The recovery cost was estimated to be 5-10 times of that from mining uranium. More than 80 percent of the total cost was covered by the cost for marine equipment for mooring the adsorbents in seawater and the corresponding weight of the metal cage for adsorbents. The cost can be reduced to one half by the reduction of the equipment weight to 1/4. Improvement of adsorbent ability is also an issue for future research since the cost depends on the adsorbent performance.

Different methods of mooring the adsorbent were investigated, and the cost of each estimated. It would cost between 30,000 and 56,000 yen to recover one kg of uranium from seawater. At an exchange rate of the yen at 100 yen / dollar, the recovery cost would be between \$250 and \$135 per ton.

There exists approximately 4.5 billion tons of uranium in the sea. The consistent 3.3 ppb uranium concentration in seawater is in chemical equilibrium. If it is depleted, we would expect that additional uranium would be leached and put in solution from ocean bottoms, hydrothermal vents and cold seeps, and terrestrial sources primarily through tidal pumping on the continental shelves, with some from rivers and other discharges. If we extracted a billion tons over hundreds of years, it is more likely that the oceans will continue containing nearly 4.5 billion tons than be reduced to 3.5 billion tons. That makes it a renewable energy resource indeed.

Estimates of the amount of uranium in the Earth's crust are 40 trillion tons. If there is a chemical equilibrium between crustal uranium and uranium in the sea, the uranium supply in the sea will keep on replenishing as long as the Earth lasts. Even better, thorium is about 4 times more plentiful than uranium in the Earth's crust.

Using an economical resource-base model, Cliff Singer estimates that there may exist 19 million tonnes of uranium resource base recoverable at up to \$130/kg at 1996 prices. It is considered that uranium costing less than \$80/kg would compete with the use of the Mixed Oxide (MOX) of Pu²³⁹ and U²³⁵, and at larger than \$130/kg would compete with breeding. Gopi Rethinaraj used Princeton Geologist Dreyfus scaling of resources sizes to the 2.3 power of extraction cost, and suggests very large amounts of uranium available up to the \$300-400/kg at 2005 prices where reprocessing and seawater extraction become competitive with land based uranium mining and byproduct recovery such as from phosphate minerals and gold. At this cost level of seawater extracted uranium, the busbar cost of nuclear electricity is estimated to increase by about 15 percent.

To improve on the plastic substrate and the compounds that fix onto the uranium, waste shrimp shells can make an effective biodegradable adsorbent material.

Table 7. Mineral content of 1 trillion (10¹²) gallons of pumped sea water per year.

Mineral Content	Tons/(10 ¹² gallons sea water)
Salt, NaCl	1.0x10 ⁹

Magnesia	76.0x10 ⁶
Potash	18.0x10 ⁶
Bromine	2.5x10 ⁶
Strontium	5.0x10 ⁵
Boron	1.9x10 ⁵
Fluorine	5.0x10 ⁴
Rubidium	7.6x10 ³
Lithium	3.8x10 ³
Barium	3.4x10 ³
Iodine	1.9x10 ³
Copper	950
Zinc	900
Molybdenum	600
Manganese	380
Titanium	340
Lead	300
Vanadium	270
Nickel	230
Arsenic	190
Selenium	150
Uranium	125
Tin	115
Chromium	95
Cesium	75
Gallium	20
Antimony	8
Bismuth	8
Silver	6
Cobalt	4
Tungsten	4
Mercury	1
Gold	600 lbs

UNDER-OCEAN FRESH WATER RESOURCES

Vincent Post, from Australia's Flinders University, in a study published in Nature, reported that an estimated 500,000 cubic kilometers or 120,000 cubic miles of low-salinity water had been found buried beneath the seabed on continental shelves off Australia, China, North America and South Africa: "The volume of this water resource is a hundred times greater than the amount we've extracted from the Earth's sub-surface in the past century since 1900. Freshwater on our planet is increasingly under stress and strain so the discovery of significant new stores off the coast is very exciting. It means that more options can be considered to help reduce the impact of droughts and continental water shortages."

The study findings were drawn from a review of seafloor water studies done for scientific or oil and gas exploration purposes. The freshwater below the seafloor is a common finding, and not some anomaly that only occurs under very special circumstances.

The deposits were formed over hundreds of thousands of years in the past, when the sea level was much lower and areas now under the ocean were exposed to rainfall which was absorbed into the underlying water table. When the polar icecaps started melting about 20,000 years ago these coastlines disappeared under water, but their aquifers remain intact -- protected by layers of clay and sediment.

The deposits were comparable with the bore basins currently relied upon by much of the world for drinking water and would cost much less than seawater to desalinate. Drilling for the water would be expensive, and great care would have to be taken not to contaminate the aquifers.

ATMOSPHERIC WATER

Water in the troposphere, as the lowest layer of the atmosphere, contains about 13,000 cubic kilometers of fresh water in the form of water vapor. This is 6 times the amount of water in the streams and rivers worldwide. If 6.6 billion people use 12 gallons per day each, they would consume only 0.0025 percent of the atmospheric water.

Atmospheric water extraction of the humidity in the air can become a future fresh water supply using refrigeration with solar and wind energy sources. In a Reverse Osmosis filtration process multi-layer membranes can filter water under high pressure from refrigerated high humidity air.

DEVELOPMENT PROJECTS

Multiple designs for modular nuclear power units can be adapted for desalinating seawater. The Asea Brown Boveri (ABB)-Siemens pebble bed reactor, so named for its spherical fuel pebble bed design, uses a thorium fuel cycle. California-based General Atomics has proposed a modular, helium-cooled unit which is sited entirely underground. A portion of the energy from either type of unit at about 135 MWs, can be handily used for desalinating seawater, and units can be added as required. With four nuclear power units per installation, only 20 such complexes could desalinate 3,500 million cubic meters of water for the disputed Jordan River water basin, the equivalent of a second Jordan River. In Jordan, heavily reliant on foreign aid, its parliament rejected nuclear electrical and desalination plans as "hazardous and costly."

The Kingdom of Saudi Arabia is pressing ahead with an ambitious plan to develop nuclear power to meet rising electricity demand and save oil for export. Saudi Arabia has built a foreign assets cushion of around \$500 billion from oil exports. Increased demand for energy consumption, coupled with a rising population, is leading Saudi Arabia to burn even more of its fossil natural resources at home rather than selling them abroad and adding to the proceeds of the half-trillion-dollar cash reserves. Unless action is taken, Saudi Arabia could find it needs the petroleum price to reach \$320 a barrel by 2030 just to balance the budget.

In 2010, the King Abdullah Center for Atomic and Renewable Energy, known as KAcare, was established to oversee the Saudi Arabia's nuclear program. In 2010 it took 3.4 million barrels of oil equivalent a day (boe/d) to power electricity generation. This is expected to more than double by 2028 to 8.3 million boe/d. The aim of the Saudis' \$100 billion nuclear program is to achieve an

electricity output of 110 GigaWatts (GWs) by 2032. In 2009, the latest data available, Saudi electricity capacity was 52 GWs from 79 power stations.

At least 13-16 nuclear reactors, each costing around \$7 billion, are planned, with the first producing by 2019. Some estimates state the kingdom, the world's largest oil exporter, will burn as much as 1.2 million barrels of oil daily on electricity production, almost double the 2010 total, to meet domestic and industrial demand. The Saudis are driving to build an industrial infrastructure to sustain the economy when the oil fields get eventually depleted. Some have already begun to decline. For total reliance on nuclear power, 40-60 reactors would be needed by 2030. That is 4-6 reactors per year from 2020. In an energy mix including fossil fuels as the primary energy source, with wind, solar and nuclear power capabilities, solar power projects should produce 41 GWs within 20 years with geothermal and waste-to-energy systems providing 4 GWs.

The United Arab Emirates (UAE) launched its nuclear energy program in 2009 for producing electricity without a missing desalination objective. It is the most advanced in the Arab world, with Saudi Arabia's running second. The United Arab Emirates' \$30 billion program with \$10 billion more than originally planned is smaller in scale than that in Saudi Arabia. Both states benefit from political stability and vast financial reserves. Other regional states are less fortunate. Bahrain, Qatar, Kuwait, Egypt and Jordan all have announced plans to invest in nuclear energy to crank up electricity generation but all have lagged behind or scrapped their programs because of lack of funds or foreign investment. Kuwait has the cash, but it has been through eight governments in the past six years.



Figure 38. Al Khaluf Reverse Osmosis desalination plant, Gulf Coast. Source: Video clip, BBC.

United Arab Emirates (UAE) Nuclear Energy Corp., the state-owned company received a \$2 billion loan from the USA Export-Import Bank. The loan to the Barakah One Co., a unit of Emirates Nuclear, will pay for American products and services used in the construction of four 1,400 megawatt reactors. Westinghouse Electric Corp., based in Pittsburgh, Pennsylvania, a Toshiba, Japan unit, will supply some of the equipment for the facilities. The first of the plant's four reactors contracted to South Korea builders will be ready in 2017, with each additional unit becoming operational every year through 2020.

Egypt had drawn plans to build four nuclear reactors by 2025 with a capacity of 4,000 MWe. The first plant would have a capacity of about 1,200 MWe and will be located at Al Dabaa,

on Egypt's north-west coast. The Al Dabaa area receives just 6 inches of rainfall in a year, a plan for building a nuclear and desalting pilot plant producing 150 MWe of electricity and 5 mgd of fresh water has been languishing since the early 1970s for lack of funding and an expectation for an illusory promise of foreign aid financing that never materialized. Egypt, which has an installed electrical capacity of about 23,500 MWe, needs a further 3,000 MWe to meet the country's growing demand. No specific plans for nuclear desalination are identified. Egypt remains convulsed by the political turmoil that ensued following the February 2011 overthrow of President Hosni Mubarak, then President Mohammed Mursi, its economy sagging dangerously, subject to a relenting Malthusian population explosion.

Mexico is 60 percent arid. Tunisia is desperate for fresh water supplies. Yet both countries have areas along seashores that can be developed should fresh water supplies materialize. Southern Tunisia's saline content varies from 1.5-1.7 gm/liter, and in some places it reaches 24 grams per liter. Even though 2.5 gm/liter is usually not considered unpalatable, the USA Public Health Service suggests that drinking water should not contain more than 0.5 gm/liter.



Figure 39. Carlsbad, California Reverse Osmosis Desalination Project's 10-mile water pipeline uses 2,000 pressure vessels and is the largest desalination plant in the Western Hemisphere.

The Carlsbad, California Reverse Osmosis Desalination Project will serve the San Diego County Water Authority starting 2016, providing 50 million gallons of water per day to as many as 300,000 San Diegans cost \$1 billion upon completion. The county has turned to desalination as California continued to battle its fourth-consecutive year of drought.

The salt byproduct will not harm sea life, however, upon intake, larvae will be pulled into the plant with water, amounting to about a pound and a half of fish per day, or the daily diet of one brown pelican.

Several localities either considered or built desalination facilities along the California Coast amid periods of extended drought in the 1980s, according to the California Department of Water Resources. Santa Barbara's Charles E. Meyer Desalination Plant was one of them. The plant operated from March to June of 1992 before abundant rainfall ended the drought in subsequent winters. More than a dozen more desalination facilities are in the planning stages along the California coast, with one facility in late-stage development in Huntington Beach.

EFFECT ON EARTH CRUST

In the drought affecting California in 2014, the Earth's crust slowly rose because groundwater, which kept it weighed down, had disappeared. The estimated loss of 63 trillion gallons of water raised California's mountains by more than a half inch or 1.5 cm and on average, 0.15 inches or 0.4 cm across the western USA, according to researchers at the Scripps Institution of Oceanography at The University of California in San Diego. This water loss is equivalent to the yearly water loss of the Greenland Ice Sheet. The Scripps study, done in conjunction with the USA Geological Survey, was reported in the August 21, 2014 online edition of the journal Science.

The Scripps researchers analyzed Global Positioning System (GPS) data used for earthquake monitoring in the region from 2003 to 2014. All the monitoring stations moved upwards in the most recent years, which coincided with the 2014 drought. It would take 6 - 9 inches of rain over a four-week period for the California water conditions to stabilize. Some areas needed up to 12 inches of rain to reverse the drought condition. It is noted that the rising crust has virtually no effect on the San Andreas Fault and does not increase the risk of earthquakes.



Figure 40. Dry river bed. California drought of 2013-2014.





Figure 41. Folsom Dam Lake, Sacramento, California before and after a three-year drought, January 20, 2014.



Figure 42. Fires in California associated with drought condition, January 20, 2014.

DISCUSSION

An issue facing humanity in the 21st century is how to share the 1/2 percent of usable freshwater to feed its increasing population. A predicted 40 percent shortfall is predicted in the freshwater supply. By 2050, according to United Nations (UN), 9 billion people, compared with the present 7 billion would need to be fed using far less fresh water than we have available today.

According to Marc Bierkens of the Utrecht University in Utrecht, the Netherlands: “If you let the population grow by extending the irrigated areas using groundwater that is not being recharged, then you will run into a wall at a certain point in time, and you will have hunger and social unrest to go with it. That is something that you can see coming for miles.”

The advances in technology, innovation, and best practices/conservation are clashing with finite water resources, relentless population growth, changing diets, a lack of investment in water infrastructure and increased urban, agricultural and industrial water usage. Investment in water management as a percentage of Gross Domestic Product (GDP) has dropped by 1/2 in most countries since the late 1990s.

Current estimates indicate that the world will not have enough water to feed ourselves in a 25-year time-span, according to the International Water Management Institute (IWMI). The central issue over the next few decades will be whether humanity can achieve and sustain the food harvest needed to feed the world population.

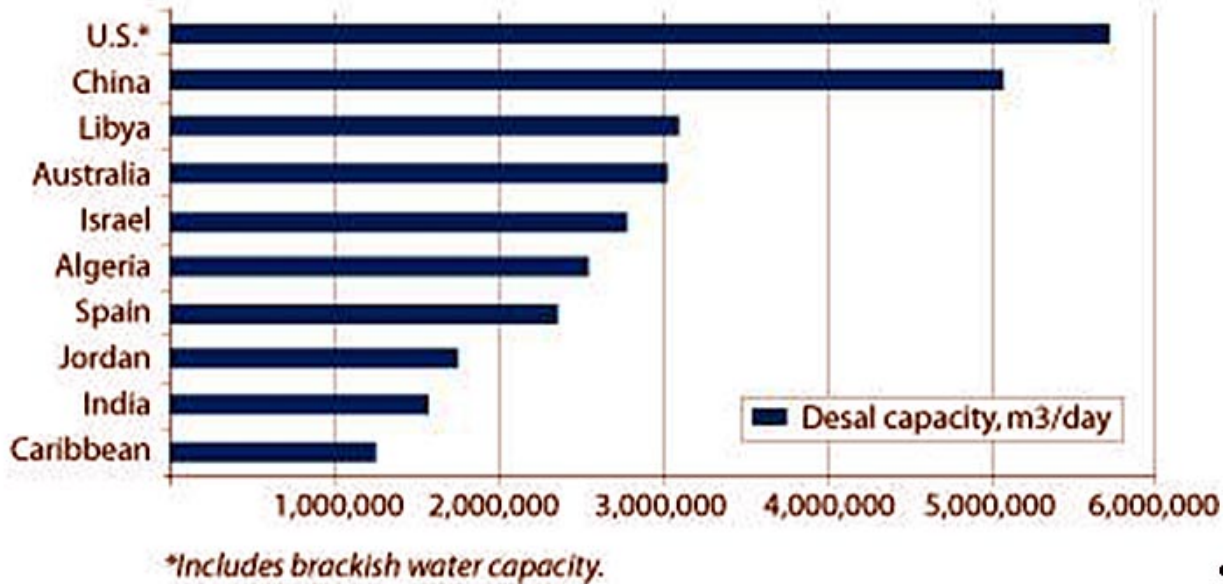


Figure 43. Desalination capacity in m³ / day in the top 10 desalination markets in the world.

To ensure a reliable water supply in the USA will require a significant infrastructure upgrade. Upgrading pipelines to accommodate the needed new supply is estimated to require \$300 billion over a 30 years period or \$10 billion/year.

In his book “Future of Life on Earth,” John Cairns Jr. states: “One lesson from the great global extinctions is that species and ecosystems come and go, but the evolutionary process continues. In short, life forms have a future on Earth, but humankind’s future depends on its stewardship of ecosystems that favor Homo sapiens.” The gap between human demand of fresh water supplies and its available supply has reached the critical threshold of an unsustainable “ecological overshoot.”

Fresh water is in short supply in most parts of the world, even more than electrical energy, and the future will certainly witness a role for nuclear, solar and wind energy in alleviating the shortage. Over the next few decades, fresh water shortages, in addition to climate change will determine whether humanity can sustainably feed its masses.

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