Chapter 1

Water and its global context

Water – a tasteless, odorless, simple chemical compound (H_2O) – is the most important commodity on Earth. It is 'key to life as we know it' (1) and has always been a focus of human attention. In fact the pre-Socratic Greek philosopher Thales of Miletus put forward his 'cosmological thesis' that 'the originating principle of nature and the nature of matter was a single material substance: water.' (2) In modern times water has also been the focus of our search for life on other planetary bodies.

1.1 EARTH'S WATER RESOURCES

The Earth is a water-rich planet. The estimated total volume of water is more than 300 million cubic miles, each cubic mile contains more than 1 trillion gallons (10^{12} gallons, approximately 3.78 teralitres), and water covers 71% of the Earth's surface. Along with energy, water is one of the two

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essential ingredients of sustainable economic development. However, there is one critical difference between the two: while energy can be derived from a variety of resources, there is no substitute for water. The Arab saying ‘water is life’ is a truism – without water you die.

Given the large amount of water on Earth, which has been constant for at least hundreds of millions of years, why are people concerned about water supply? The biggest problem is that most of that water, approximately 97%, is found in the oceans (seawater), with an average salt concentration of 35,000 parts per million (ppm). People and animals cannot drink that water for any length of time without dehydrating internally – the body extracts water from its cells to dilute the ingested salt – and eventually dying from organ failure. Salty (saline) water, such as that found in the oceans, must be desalted (desalinated) to a level at or below 1000 ppm for human and animal consumption. Saline water can also impose limits on agricultural production.

Of the remaining 3–4% of water on the Earth that is fresh, most is not easily available for our use. Over two-thirds is tied up in glaciers, polar ice caps, and permanent snow cover in mountainous regions, and the rest as groundwater in lakes and rivers, and as water vapor in the atmosphere – and even much of the groundwater is at unreachable locations and depths. The net result is that we make productive use of less than 1% of our global water resources.

1.2 SALINE WATER AND DESALINATION PROCESSES

Saline water is characterized into three broad categories:

- Highly saline water: more than 10,000 ppm
- Brackish water: 1000–10,000 ppm
- Freshwater: less than 1000 ppm

How does one remove salt from highly saline or brackish water to produce drinkable (potable) water? Quite a few technologies exist to do this separation, the oldest being sun-heated water that evaporates and is then condensed on a cold surface, leaving the salt behind. (*Note*: this also describes the first stage of the Earth's hydrologic cycle, in which sun-heated water evaporates from the oceans and other bodies of water into the atmosphere.) References to this process of evaporation and condensation, known as distillation, can be found in historical records going back centuries. Variations are widely used at sea today and, in the past, helped keep many early explorers and traders alive during long ocean trips. A modern-day example is a United States nuclear-powered aircraft carrier that uses waste heat from its nuclear reactor to desalinate 400,000 gallons of seawater per day.

The technologies used to perform this separation can be categorized broadly as either thermal or membrane technologies. The most popular today is reverse osmosis (RO) in which a pressurized stream of saline water is forced through a membrane which allows the small water molecules to pass through, but not the various salts found in brackish water or sea water. Several stages of such separation can lead to freshwater at or below the 1000 ppm level of salt. Other major desalination technologies are listed in Table 1.1.

Table 1.1 Desalination technologies.

Thermal Technology
• multi-stage flash distillation (MSF)
• multi-effect distillation (MED)
• vapor compression distillation (VCD)
Membrane Technology
• reverse osmosis (RO)
• electrodialysis (ED)
• electrodialysis reversal (EDR)

Multi-stage flash (MSF) distillation occurs in several successive stages, each at a progressively lower pressure. The feed water is first heated at high pressure, and the lower pressures in successive stages result in a sequence of sudden evaporation and condensation. In multi-effect distillation (MED), which uses the same principle of evaporation and distillation at progressively lower pressures, the water vapor of each vessel ('effect') serves as the heat source for the next vessel. Another variation is vapor compression distillation (VCD), where mechanical compression is used to generate the heat for evaporation.

In addition to RO, other membrane technologies are electrodialysis (ED) and electrodialysis reversal (EDR), both of which predate RO. Both are voltage-driven processes which utilize the fact that salts dissolved in water are electrically charged ions (either positive or negative). For example, in a saline solution containing dissolved sodium chloride, the sodium ion has a positive charge (cation) and the chloride ion a negative charge (anion). Applying a voltage across the ED membrane allows either a cation or an anion to pass through the membrane, leaving diluted water behind. In EDR the polarity of the driving voltage is reversed several times an hour. Once the desired water quality is achieved and the desalinated water is removed, the concentrate channels are flushed and clean water production resumed.

The RO process is a variation on osmosis, the phenomenon in which water with a low-salt concentration passes naturally through a semi-permeable membrane into a region of higher salt concentration. By applying pressure to the solution with a higher salt concentration, the water is forced to flow in a reverse direction through the membrane, leaving the salt behind. The required pressures range from about 150 pounds per square inch (psi), roughly equivalent to 1035 kPa, for low-salinity brackish water up to 800–1000 psi (5515–6895 kPa) for high-salinity seawater.

1.3 ENERGY REQUIREMENTS AND COSTS OF DESALINATION

How much does it cost to desalinate salty water? Figure 1.1 shows a typical breakdown of costs for seawater desalination showing that energy is one of the largest cost factors:

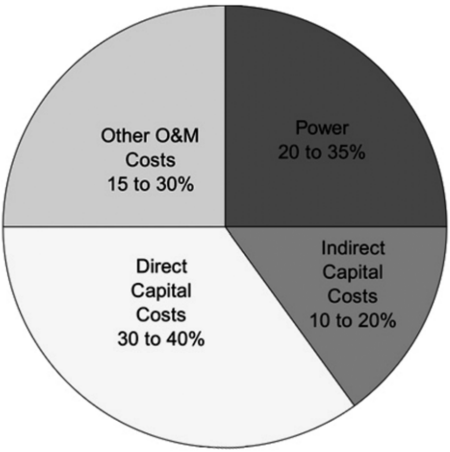

Figure 1.1 Breakdown of costs for seawater desalination (3).

Energy requirements (electrical + thermal) for a range of saline waters are shown in Table 1.2 for various desalination technologies (these figures do not include the energy required for pre-treatment, brine disposal and movement of water).

Table 1.2 Energy consumption for desalination technologies (4).

Technology	Total Equivalent Electrical Energy (kWh/m^3)
MSF	13.5–25.5
MED	6.5–11
VCD	7–12
RO	3–5.5

In recent years much effort has gone into reducing the costs of desalination, as its global importance has grown. Even though currently it only provides about 1% of the word's drinking water, this fraction is growing steadily, and desalination is increasingly recognized as a reliable, drought-proof source of potable water for coastal communities worldwide. Energy costs have been reduced by approximately 80% over the past two decades, and are projected to decrease by up to a further 60% in the next 20 years. These costs today range from 40 to 100 US cents per cubic metre (1000 litres) of freshwater. Nevertheless, while 'Today, the energy needed to produce freshwater from seawater for one household per year is less than that used by the household's refrigerator' (5), that cost is still higher, on average, than the cost of deriving freshwater from groundwater, water recycling or water conservation.

The International Desalination Association (IDA) reports that worldwide at the end of 2015 there were more than 18,000 desalination plants in 150 countries, producing about 87 million cubic metres of freshwater every day. About 44% of this capacity is located in the Middle East and North Africa (MENA). It is estimated that more than 300 million people currently rely on desalinated water for some or all of their daily needs.

1.4 DEMAND FOR FRESHWATER

Two important questions are: how is global demand for freshwater changing, and what are the implications when freshwater supplies are limited? Some people have identified access to freshwater as the 21st century's analog to the burning issue of access to petroleum supplies in the previous century.

During the 20th century, global population tripled while the human demand for freshwater increased by a factor of six. That demand tripled in the past 50 years alone. Providing that much water has significant environmental impacts, which will be discussed in Chapter 4. Today, on average, a little over two-thirds of global water withdrawals (70%) are for agriculture, while 20% are for industrial use and 10% for municipal use. In developing countries the percentage of water used for agriculture is even higher.

Figure 1.2 shows historic and projected world water demand from 1980 to 2030. It shows that current annual withdrawals are of the order of 5000 km^3, or about 30% of the estimated 14,000 km^3 of easily accessible freshwater.

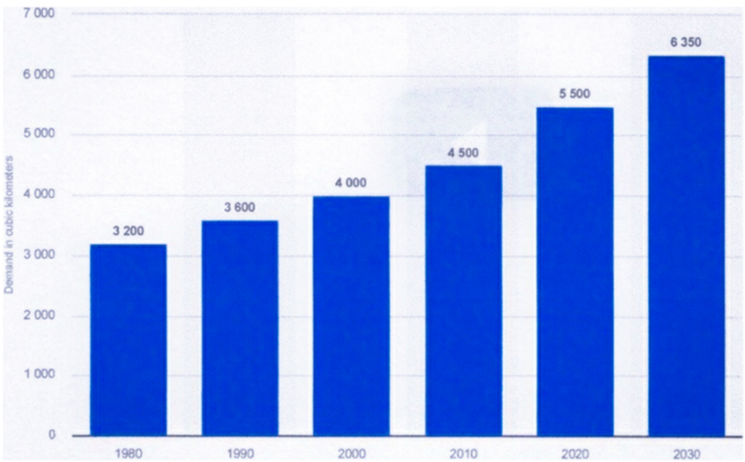

Figure 1.2 Historic and projected water demand (cubic kilometres) (6).

Thus, in theory there is enough freshwater to meet not only the current demand, based on a population of just over 7 billion, but also an increasing demand from a future population that may reach 9–10 billion by 2050. A related consideration is that 'the world's middle class is expected to grow from less than 2 billion in 2014 to nearly 4.9 billion by 2030, with even more growth by 2050. As this more affluent population increases, demand for water will surge – not least owing to a greater appetite for meat and other goods that are more water-intensive to produce. In developing countries, where the vast majority of both population growth and rising incomes can be found, a 50% increase in water withdrawals is expected by 2025, while developed countries will increase by 18%. As a result, as UN-Water highlights, water use continues to expand at more than twice the rate of population growth (7).'

An additional consideration, with major implications for global tensions, is that freshwater resources are not distributed uniformly around the globe, either in time or geography. Some locations have large resources of freshwater, and some have little or none. Even where resources exist, water scarcity can exist during specific times of the year – for example, when snow melt at one time cannot be captured for use at another time. It does not then come as a surprise that the struggle to control water resources has shaped human economic and political history. Globally, the 215 international rivers and 300 groundwater basins that are shared by two or more countries have often generated tensions. For example, in the volatile Middle East, water is a source of conflict not only between the Israelis and Palestinians, but also between Egypt and Sudan, and among Turkey, Syria and Iraq. Such tensions also exist between several states in the US, and elsewhere as well.

It is also important to recognize that the precipitation (rainfall) patterns that bring much of the world's freshwater will change as a result of global warming and climate change, often with adverse consequences. A more comprehensive discussion of this topic can be found in Chapters 4 and 10. Over-pumping and depletion of underground aquifers, as well as contamination of freshwater sources, are also serious concerns. It is estimated that withdrawals by farmers in India, China, the US, and elsewhere already exceed natural replenishment by 4%, and that gap is growing. Industrial, municipal, and agricultural runoff are contaminating existing freshwater sources, requiring water treatment before reuse.

1.5 IMPLICATIONS OF LIMITED ACCESS TO FRESHWATER

The implications of limited or no access to freshwater are significant, not only for food production but also for public health. Unfortunately, reliable data on clean water access and sanitation practices for parts of the developing world are still hard to come by. The 2017 report of the WHO/UNICEF Joint Monitoring Program on Drinking Water, Sanitation and Hygiene (8) estimates that in 2015 '844 million people still lacked even a basic drinking water service … 159 million people still collected (potentially contaminated) water directly from surface water sources/58% lived in sub-Saharan Africa … 2.3 billion people still lacked even a basic sanitation service' … 892 million people still practiced open defecation.'

An additional challenge is posed by increasing urbanization, the population shift from rural to urban areas. Seen as an inevitable consequence of the industrial revolution, it has major implications for delivery of water services. Currently more than half of the world's population lives in urban areas, and this fraction is expected to increase to 70% by 2050. In 1970 Tokyo and New York were the only cities with a population greater than 10 million people, so-called megacities. Today, there are 13 megacities in Asia, four in Latin America, and two each in Africa, North America, and Europe. Many of these cities are already experiencing severe water stress and their situations will only worsen. Water stress (sometimes referred to as water scarcity) can be defined as the inability to meet human and ecological demand for freshwater. The minimum quantity of water deemed necessary to satisfy basic human needs ranges from 20 to 50 litres (7.3–18.3 m^3) per person per day, depending on what is included in 'basic needs'. Many countries already fall below that level – water shortages currently plague almost every every country in MENA – and experts project that, under 'business as usual', close to 2 billion people in

39 countries will still face serious freshwater shortages in mid-century.

In the developing world it is estimated that waterborne diseases account for almost 80% of infections, causing more than 3 million premature deaths. Approximately 5000 children die from diarrhea every day (one every 17 seconds) and many more are stunted in their development as a result of recurrent diarrheal episodes. In addition, several hundred million people are infected with the parasitic disease schistosomiasis (snail fever disease), an estimated 880 million children are in need of treatment for intestinal worms, and an estimated 1.9 million people are blind from trachoma (caused by infection with the bacteria *Chlamydia trachomatis*) with an at-risk population in 41 countries of 190 million (9).

1.6 ACTIONS TO INCREASE ACCESS TO FRESHWATER

Many voices have tried to sound the alarm on growing water issues, especially in recent years. World Water Forums, hosted by the World Water Council, have been held every three years since 1997. The UN Millennium Summit in New York in 2000 identified water availability as a critical global issue, as did the 2002 World Summit on Sustainable Development in Johannesburg. The UN declared 2003 the International Year of Freshwater, and designated the period 2005–2015 the UN Decade of Water.

At its 2000 Summit the UN adopted a series of Millennium Development Goals (MDGs), two of which dealt with water issues: 'to reduce by half, by 2015, the proportion of people without access to (a) safe drinking water and (b) basic sanitation.' Assuming a world population in 2015 of 7.2 billion implied that, by 2015, 1.6 billion more people would need to be supplied with access to safe drinking water and an additional 2.2 billion to basic sanitation. Even if achieved, these goals still would have left 600 million people without access to safe drinking water and 1.5 billion without access to basic sanitation. The safe drinking water goal was met in 2010, but the basic sanitation goal is yet to be achieved in more than 70 countries.

In 2011 the InterAction Council (IAC), a high-level group of former national leaders that has met annually since 1963, warned of an impending 'water crisis' and established a panel to address what they saw as a worldwide leadership gap on the issue. In 2012 the panel released a report, 'The Global Water Crisis: Addressing an Urgent Security Issue' (10).

In the foreward to the report, Gro Harlem Brundtland, the former Prime Minister of Norway and IAC Chair, underlined the danger in many regions where critical shortages already exist – sub-Saharan Africa, West Asia, and North Africa: 'As some of these nations are already politically unstable, such crises may have regional repercussions that extend well beyond their political boundaries. But even in politically stable regions, the status might very well be disturbed first and most dramatically by the loss of stability in hydrological patterns.' IAC co-Chair Jean Chretien, former Canadian Prime Minister, added, when the report was released, that 'The future political impact of water scarcity may be devastating. Using water the way we have in the past will not sustain humanity in the future. The IAC is calling on the United Nations Security Council to recognize water as one of the top security concerns facing the global community. Starting to manage water resources more effectively and efficiently now will enable humanity to better respond to today's problems and to the surprises and troubles we can expect in a warming world.'

1.7 GENDER EQUITY ISSUES

To complete this overview of water issues I turn to the important issue of gender equity. In the context of this chapter 'gender' is a social and not a biological concept: for our purposes it refers to a set of relations which define social function and power on the basis of gender identity. This implies that gender-based relations can be changed. While these relations are not inherently oppressive, all too often they have been oppressive of women. Where gender equity is missing – that is, where women and men do not have equal opportunity to realize their full human rights and potential – there are serious negative consequences for development and for addressing issues related to water scarcity.

Women head one-third of the world's families (and more than half of the families in Latin America) and frequently are the principal water providers and income producers for their families. They are responsible for half of the world's food production, and produce a majority of the food in most developing nations. To produce this food and have adequate sanitation for their families they must first 'produce' water. They do this in many cases by spending several hours a day hauling water, time that could be better spent on education, cottage industries, and community development. If safe and reliable water sources do not exist within reach, they are forced to rely on often contaminated local water supplies or pay exorbitant prices to local water vendors. This has major implications for hygiene and the spread of diseases among poor women and their families. Finally, poor women's access to water in many communities is less than that of men because decisions are most likely made by men, and the needs of women are often ignored or undervalued. This has led to a situation where women are the poorest of the poor in many parts of the world, creating what has come to be called the 'feminization of poverty'.