CHAPTER 1

Peak Water

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In the past few years, discussions about the possibility of resource crises around water, energy, and food have introduced new terms and concepts into the public debate. Energy experts predict that the world is approaching, or has even passed, the point of maximum production of oil, or "peak oil." The implications of reaching this point for energy policy are profound, for a range of economic, political, and environmental reasons. More recently, there has been a growing discussion of whether we are also approaching a comparable point of "peak water," at which we run up against natural limits to availability or human use of freshwater.

To judge from recent media attention, the finite supply of freshwater on Earth has been nearly tapped dry, leading to a natural resource calamity on par with, or even worse than, running out of accessible, affordable oil. In this chapter, we evaluate the similarities and differences between water and oil to understand whether and how the concept of "peak water" is analogous to the idea of peak oil; how relevant this idea is to actual hydrologic and water management conditions; and the implications of limits on freshwater availability for human and ecosystem well-being.

Regional water scarcity is a significant and growing problem although there are many different (and often inconsistent) measures and indicators of water scarcity (Gleick et al. 2002). In some regions, water use exceeds the amount of water that is naturally replenished every year. About one-third of the world's population lives in countries with moderate-to-high water stress, defined by the United Nations to be water consumption that exceeds 10 percent of renewable freshwater resources. By this measure, some 80 countries, constituting 40 percent of the world's population, were suffering from water shortages by the mid-1990s (CSD 1997, UN/WWAP 2003). By 2020, water use is expected to increase by 40 percent, and 17 percent more water will be required for food production to meet the needs of the growing population. According to another estimate from the United Nations, by 2025, 1.8 billion people will be living in regions with absolute water scarcity, and two out of three people in the world could be living under conditions of water stress (UNEP 2007). Are we reaching natural limits to growth, long predicted by some observers? Are there peaks in availability or use of certain resources? These questions have long been debated in the energy field, and they are now being raised for other vital resources, particularly water.

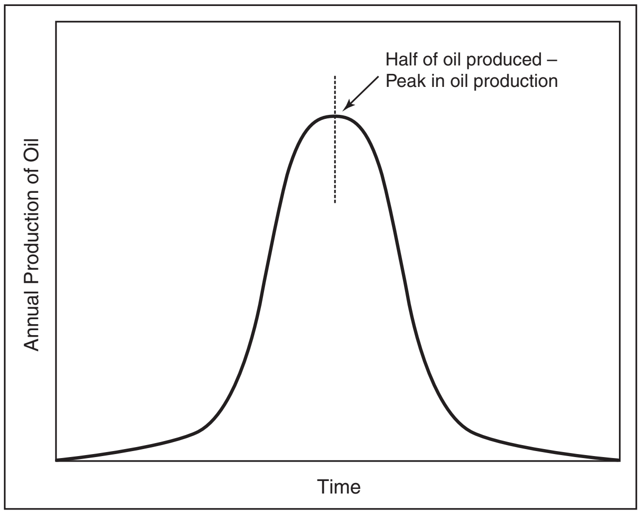

FIGURE 1.1 HUBBERT CURVE FOR AN OIL-PRODUCING REGION.

Concept of Peak Oil

The theory of peak oil originated in the 1950s with the work of geologist M. King Hubbert and colleagues who suggested that the rate of oil production would likely be characterized by several phases that follow a bell-shaped curve. First, discovery and the rate of exploitation rapidly increase as demand rises, production becomes more efficient, and costs fall. Second, as oil is consumed, the resource becomes increasingly scarce, costs increase, and production levels off and peaks. Finally, increasing scarcity leads to a decline in the rate of production more quickly than new supplies can be found. This last phase would also be typically accompanied by the substitution of alternatives (Ehrlich et al. 1977). The phrase "peak oil" refers to the point at which approximately half of the existing stock of petroleum has been depleted and the rate of production peaks (Fig. 1.1).

In 1956, Hubbert predicted that oil production in the United States would peak between 1965 and 1970. And, in fact in 1970, oil production in the U.S. reached its height and began to decline (Fig. 1.2). The concept of a bell-shaped oil production

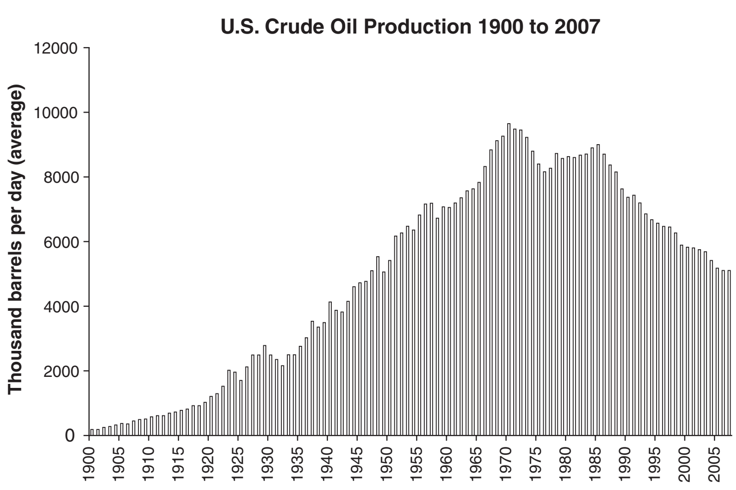

FIGURE 1.2 U.S. CRUDE OIL PRODUCTION 1900 TO 2007.
Source: USEIA 2007.

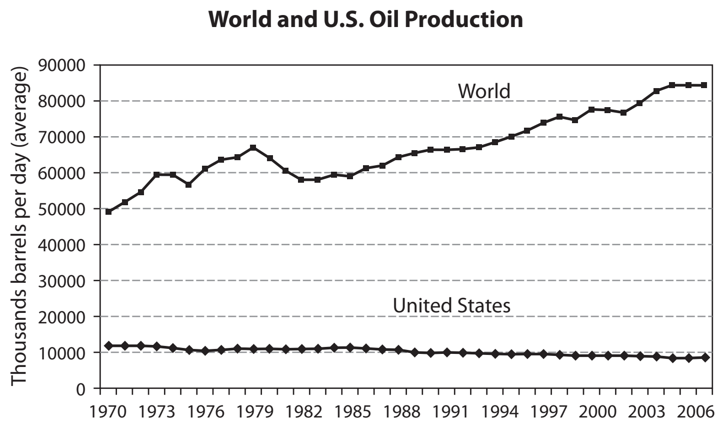

Figure 1.3 World and U.S. Oil Production 1970 to 2007.
Source: USEIA 2008.

curve has been proven for a well, an oil field, a region, and is thought to hold true worldwide. The theory of peak oil also envisions that once half of oil reserves have been produced, oil would become increasingly more difficult and expensive to extract because the most accessible sources of petroleum had already been tapped.

In recent years, the concept of peak oil has received renewed attention because of growing concern that the world as a whole is approaching the point of declining petroleum production. No one knows when global oil production will actually peak, and forecasts of the date range from early in the 21st century to after 2025. One of many recent estimates suggests that oil production may peak as early as 2012 at 100 million barrels of oil per day (Gold and Davis 2007). The actual peak of production depends on the demand and cost of oil, the economics of technologies for extracting oil, the rate of discovery of new reserves compared to the rate of extraction, the cost of alternative energy sources, and political factors. Figure 1.3 shows total U.S. and global oil production from 1970 to 2007.

There are many reasons for growing concern over reaching the point of maximum production of oil. In particular, the population of the planet continues to grow rapidly, driving rising demand for energy in the form of liquid fuels. This growing demand, together with the fact that alternatives or substitutes for oil remain economically expensive and technologically immature, raises the specter of energy shortages, constraints on industrial activity, and economic disruptions. And in summer 2008, when the price of oil shot to $140 per barrel, the concept of peak oil began to feel all too tangible.

Comparison of Water and Oil

Does production or use of water follow a similar bell-shaped curve? In the growing concern about global and local water shortages and scarcity, is the concept of "peak water" valid and useful to water planners, managers, and users?

In the following sections, we consider the differences and similarities between oil and water to evaluate whether a peak in the production of water is possible, and in what contexts it may be relevant. We assess existing limits to the amount of water and

Table 1.1 Summary Comparison of Oil and Water

Characteristic	Oil	Water
Quantity of resource	Finite	Literally finite, but practically unlimited at a cost
Renewable or non-renewable	Non-renewable resource	Renewable overall, but with locally non-renewable stocks
Flow	Only as withdrawals from fixed stocks	Water cycle renews natural flows
Transportability	Long-distance transport is economically viable.	Long-distance transport is not economically viable.
Consumptive versus non-consumptive use	Almost all use of petroleum is consumptive, converting high-quality fuel into lower quality heat.	Some uses of water are consumptive, but many are not. Overall, water is not "consumed" from the hydrologic cycle.
Substitutability	The energy provided by the combustion of oil can be provided by a wide range of alternatives.	Water has no substitute for a wide range of functions and purposes.
Prospects	Limited availability; substitution inevitable by a backstop renewable source	Locally limited, but globally unlimited after backstop source (e.g., desalination of oceans) is economically and environmentally developed.

oil available on earth. Oil and water are also compared in terms of the renewability of the resource, whether the substance is consumed or not during use, and whether its use is global or local in scale. We also look at whether substitutes for the resources are possible. Our major findings are summarized in Table 1.1. Based on this analysis, in the next section we evaluate the utility of the term "peak water."

First, we look at the question of limits on total water availability. While it is clear that we will at some point in the future run out of oil (or, to be more precise, economically and environmentally accessible oil), will we run out of water? Considering this question on a planet covered with water may seem odd, but as the following section illustrates, there are distinct differences in the amount of water that exists in stocks versus that which is available in flows of the hydrologic cycle.

Are We Running Out of Water?

The total quantity of both water and oil on Earth are literally limited, though the more important question is whether they are practically limited. The origins of petroleum rest with biological and chemical processes that turned decaying plant carbon into stocks of liquid and solid "fossil fuels" over the geologic time of millions of years. The origins of water on Earth are less certain, but most geologists agree that the water on the planet is of cosmic origins from around the time when the planet itself was formed (Box 1.1).

How much water is there on Earth and where is it? Table 1.2 shows the distribution of the main components of the world's water. The Earth has a stock of approximately

Box 1.1 The Origins of Water on Earth

A healthy academic debate continues over the origins of water on Earth. At present, the evidence suggests that at least a substantial amount of the world's water originated billions of years ago during the formation of the planet itself. Drake and Campins argue that the evidence is strong that the Earth had a proto-atmosphere and large bodies of water as far back as 4.45 billion years ago, but there is also evidence of later accretion of water from comets and meteors (Robert 2001, NASA 2001, Drake and Campins 2006). Among the ideas about the origins of the planet's water resources are:

- As the Earth cooled, the temperature reached a point where gases released from cooling terrestrial materials could be retained in an atmosphere whose pressure permitted the formation of liquid water.
- Water was delivered to the surface by large comets, trans-Neptunian objects, or water-rich asteroids. The presence of water in comets and outer solar system planetoids has long been confirmed, and the composition of some of this water is similar to the composition of water in the Earth's oceans. In particular, the distribution of the hydrogen isotopic ratio in carbonaceous meteorites is the most similar to the isotopic ratio found in water on Earth.
- Water was delivered to the surface by very small comets over a very long period of time. These comets continue to deliver water to the Earth.
- The release of water stored in hydrous minerals of the planet over time.

1.4 billion cubic kilometers of water, spread over a wide variety of forms and locations. Of this water, the vast majority (nearly 97%) is salt water in the oceans. The world's total freshwater reserves are estimated at around 35 million cubic kilometers. Most of this, however, is locked up in glaciers and permanent snow cover, or in deep groundwater, inaccessible to humans.

Considering the total volume of water on Earth, the concept of running out of water at the global scale is of little practical utility. There are huge volumes of water—many thousands of times the volumes that humans appropriate for all purposes. In the early 2000s, total global withdrawals of water were approximately 3,700 km^3 per year, a tiny fraction of the estimated stock of 35 million km^3 of water (Gleick 2006).

A more accurate, and sobering, way to evaluate human uses of water, however, would look at the total impact of human appropriations through the use of rainfall, surface and groundwater stocks, soil moisture, and so on. An early effort to evaluate these uses estimated that humans already appropriate over 50% of all renewable and

Table 1.2 Major Stocks of Water on Earth

	Distribution Area (10^3 km^2)	Volume (10^3 km^3)	Percent of Total Water (%)	Percent of Fresh Water (%)
Total water	510,000	1,386,000	100	
Total freshwater	149,000	35,000	2.53	100
World oceans	361,300	1,340,000	96.5	
Saline groundwater		13,000	1	
Fresh groundwater		10,500	.76	30
Antarctic glaciers	13,980	21,600	1.56	61.7
Greenland glaciers	1,800	2,340	.17	6.7
Arctic islands	226	84	.006	.24
Mountain glaciers	224	40.6	.003	.12
Ground ice/permafrost	21,000	300	.022	.86
Saline lakes	822	85.4	.006	
Freshwater lakes	1,240	91	.007	.26
Wetlands	2,680	11.5	.0008	.03
Rivers (as flows on average)		2.12	.0002	.006
In biological matter		1.12	.0001	.0003
In the atmosphere (on average)		12.9	.0001	.04

Source: Shiklomanov (1993).

"accessible" freshwater flows (Postel et al. 1996), including a fairly large fraction of water that is used instream for dilution of human wastes. It is important to note, however, that these uses are of the "renewable" flows of water, which we explain later. In theory, this use can continue indefinitely without any effect on future availability because of the renewability of the resource. Still, while water itself is renewable, many uses of water will degrade its quality to such an extent that this theoretically "available" water is practically useless. Improving the quality of this water for reuse will require the input of energy, technology, biological treatment, or dilution with more water.

Renewable vs. Nonrenewable Resources

In any comparison between oil and water, it is vital to distinguish between renewable and nonrenewable resources. The key difference between these is that renewable resources are flow (or rate) limited; nonrenewable resources are stock limited (Ehrlich et al. 1977). Stock-limited resources, especially fossil fuels, can be depleted without being replenished on a time-scale of practical interest. Stocks of oil, for example, accumulated over millions of years. How long oil lasts depends on our ability to find it, the rate we use it, and the cost of removing and using it; the volume of oil stocks is effectively independent of any natural rates of replenishment because such rates are so slow.

Flow-limited resources can be virtually inexhaustible over time, because their use does not diminish the production of the next unit. Such resources, such as solar energy, are, however, limited in the flow rate, i.e., the amount available per unit time. Our use of solar energy has no effect on the next amount produced by the sun, but our ability to capture solar energy is a function of the rate at which it is delivered.

Water is a unique renewable natural resource that demonstrates characteristics of both flow-limited and stock-limited resources, because of the wide range of forms and locations for freshwater. This dual characteristic of water has implications for the applicability of the term peak water. Overall, water is a renewable resource with rapid flows from one stock and form to another, and the production of water typically has no effect on natural recharge rates. But there are also fixed or isolated stocks of local water resources that can be consumed at rates far faster than natural rates of renewal, or for which the rate of recharge is extremely slow. Most of these are groundwater aquifers—often called “fossil” aquifers because of their slow recharge rates—but some surface water storage in the form of lakes or glaciers can also be used at rates exceeding natural renewal, a problem that may be worsened by climate change, as noted later and in Chapter 3.

Consumptive vs. Non-Consumptive Uses

Another key factor in evaluating the utility of the concept of a resource peak is whether water and oil are used in consumptive or non-consumptive ways. Practically every use of petroleum is consumptive; once the energy is extracted and used, it is degraded in quality.[1] Almost every year, the amount of oil consumed matches the amount of oil produced, and sometimes we consume more than is produced that year. Thus a production curve for oil is solely dependent on access to new oil.

Not all uses of water are consumptive and even water that has been “consumed” is not lost to the hydrologic cycle or to future use—it is simply recycled by natural systems. Consumptive uses of water only refer to uses of water that make that water unavailable for immediate or short-term reuse within the same watershed. Such consumptive uses include water that has evaporated, transpired, been incorporated into products or crops, heavily contaminated, or consumed by humans or animals. As discussed in the section on the renewability of water resources, some stocks of water can be effectively consumed locally. When withdrawals are not replaced on a timescale of interest to society, eventually that stock becomes depleted. The water itself remains in the hydrologic cycle, in another stock or flow, but it is no longer available for use in the region originally found. There are also many non-consumptive uses of water, including water used for cooling in industrial and energy production, and water used for washing, flushing, or other residential uses if that water can be collected, treated, and reused.

Transportability of Water

Because the Earth will never “run out” of freshwater, growing concerns about water scarcity must, therefore, be the result of something other than a concern about literally consuming a limited resource. And, of course, they are; water challenges are the result of the tremendously uneven distribution (due to both natural and human factors) of water on earth, the economic and physical constraints on tapping some of the largest volumes (such as deep groundwater and ice in Antarctica and Greenland) of freshwa-

1. Due to the law of conservation of energy, energy is never “consumed”—simply converted to another form. But in this case, the use of oil converts concentrated, high-quality energy into low-quality, unusable waste heat, effectively “consuming” the oil.

ter, human contamination of some readily available stocks, and the high costs of moving water from one place to another.

This last point—the "transportability" of water—is highly relevant to the concept of peaking. Oil is transported around the world because it has a high economic value compared to the cost of transportation. As a result, there is, effectively a single global stock of oil that can be depleted, and regional constraints can be overcome by moving oil from the point of production to any point of use. In contrast, water is expensive to move any large distance, compared to its value. As a result, there is no single, fungible global stock of water, and regional constraints become a legitimate and serious concern.

Media attention to the concept of "peak water" has focused on local water scarcity and challenges, for good reason. But, there has been little or no academic research or analysis on this concept. In regions where water is scarce, the apparent nature of water constraints—and hence, some of the real implications of a "peak" in availability—are already apparent. Because the costs of transporting bulk water from one place to another are so high, once a region's water use exceeds its renewable supply, it will begin tapping into non-renewable resources such as slow-recharge aquifers. Once extraction of water exceeds natural rates of replenishment, the only long-term options are to reduce demand to sustainable levels, move the demand to an area where water is available, or shift to increasingly expensive sources, such as desalination.

A few exceptions to the economic limits on transporting water exist. Bottled water, for example, is sometimes consumed vast distances from where it was produced because it commands a premium far above normal costs. Growth in bottled water consumption may expand in some markets, but overall, long-distance transfers of bulk water are not likely to become a significant export in commercial markets.

Substitutes for Oil and Water

An important characteristic of peak oil discussions is the inevitable substitution of alternative energy sources for oil as production declines and prices increase. Oil serves particular functions in industrial society that can be satisfied by other means or resources (e.g., solar, natural gas, biofuels). In this sense, any depletable resource, such as fossil fuels, must be considered a transition option, useful only as long as its availability falls within economic and environmental limits.

The basic amount of water needed for drinking and growing food should be considered irreplaceable. There are also many ways that we use water that are unnecessary or highly inefficient. For example, using water to transport human waste is a choice, but not a necessary use of water.

Like energy, water is used for a variety of purposes. And like energy, the efficiency of water use can be greatly improved by changes in technologies and processes. Unlike oil, however, fresh water is the *only* substance capable of meeting certain needs. Thus, while other energy sources can substitute for oil, water has no substitutes for many uses.

A relevant concept to both peak water and peak oil, therefore, is the "backstop" price of substitutes—i.e., the price of the substitute capable of replacing or expanding the original source of supply of a resource. As oil production peaks and then declines, the price of oil will increase in the classic "supply/demand" economic response. Prices will continue to increase until the point when a substitute for oil becomes economically competitive, at which point prices will stabilize at the new "backstop" price.

Similarly, for water, as cheaper sources of water are depleted or allocated, more expensive sources must be found and brought to the user. Ultimately, the “backstop” price for water will be reached. Unlike oil, however, which must be backstopped by a different, renewable energy source, the ultimate water backstop is still water, from an essentially unlimited source—for example, desalination of ocean water. The amount of water in the oceans is limited only by how much we are willing to pay for it and the environmental constraints of using it. In some regions, desalination is already an economically competitive alternative, particularly where water is truly scarce, such as certain islands in the Caribbean and parts of the Persian Gulf (see Cooley et al. 2006).

Climate Change

Oil and water are also intricately tied to climate change, which affects the production and cost curves of both substances. Petroleum, as a fossil fuel that produces carbon dioxide when burned, is one of the major culprits driving global warming. Among the most significant consequences of climate change will be impacts on the hydrologic cycle (see Chapter 3). Such changes are already being experienced (IPCC 2007). As the climate changes, among the hydrologic impacts will be changes in precipitation intensity and duration, loss of snowpack and an acceleration of snowmelt in mountainous areas, loss of glaciers due to accelerated melt, and a risk of both more floods and droughts. Many of these factors will increase both water demand and water scarcity, affecting human and ecosystem health.

In some places, climate change will affect the renewability of local water resources. Where local communities are currently dependent on river runoff from glacier melt, the loss of glaciers over the next century will lead to a “peak water” effect: the diminishment of water supply over time. Communities dependent on groundwater recharge that suffer a decrease in recharge rate will also experience an effect akin to “peak water.” In this case, the concept of “peak water” is slightly different: it is not affected by the magnitude of human use, but by climatic factors that diminish the rate of replenishment. Similar to peak oil, however, when the stock is gone, alternative sources will have to be found.

Utility of the Term “Peak Water”

Given the physical and economic characteristics of oil and water reviewed earlier, how relevant or useful is the concept of a peak in the production of water? As described in the previous sections, the fact that the volume of extractable oil is limited, while water is essentially unlimited, means that if global water use followed a bell-shaped curve, we would never reach a “peak” in global water production. A true “peak” in resource production followed by a decline is only possible for resources that are non-renewable and consumed in their use. We cannot reach a point globally where half of water resources have been tapped because water is a renewable resource that is not consumed in its use. For these reasons, the idea of global “peak water” is inaccurate.

However, the concept can be applied in some interesting ways. In the following sections, we explore cases in which “peak water” is useful. We also introduce a new term that is useful when thinking about maximizing the multiple services that water provides: “peak ecological water.” And, we explore the value of the “peak water” concept for driving important paradigm shifts in how water is used and managed.

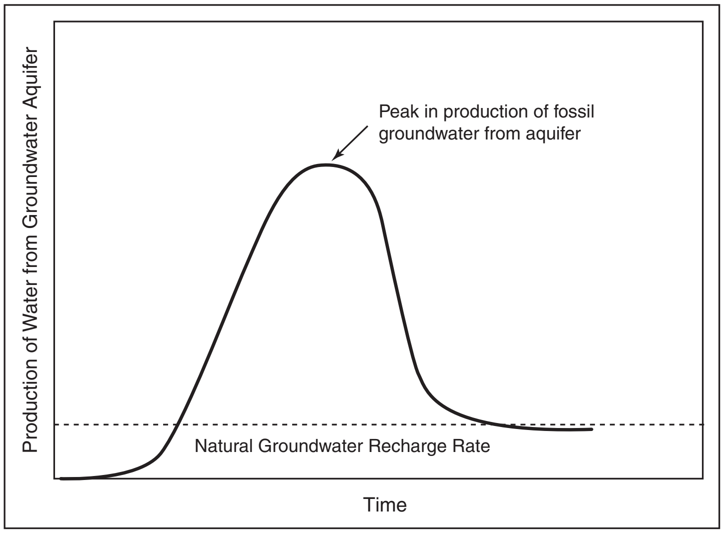

FIGURE 1.4 POTENTIAL PEAK WATER CURVE FOR PRODUCTION OF FOSSIL GROUNDWATER FROM AN AQUIFER. This theoretical curve shows the progression of water extraction from a groundwater aquifer, hypothesizing a peak oil type production curve for water after production rates surpass the natural groundwater recharge rate and production costs rise.

Fossil Groundwater

In most watersheds, there are renewable flows of water, such as rainfall, stream flows, and snow melt, and *effectively* non-renewable stocks of water, such as fossil groundwater. As defined previously, fossil groundwater is groundwater in an aquifer accumulated over many thousands of years, with a very slow recharge rate. When the use of water from a groundwater aquifer far exceeds the natural recharge rate, this stock of groundwater will be depleted quickly. In these particular situations, the groundwater aquifer is analogous to an oil field or oil-producing region. Continued production of water, beyond natural recharge rates, becomes increasingly difficult and expensive as groundwater levels drop, leading to a peak of production, followed by diminishing withdrawals and use. As shown in Figure 1.4, once withdrawals from the groundwater aquifer pass the natural recharge rate for the aquifer (shown as a dashed line), the production of water from the aquifer can continue to increase until a significant portion of the groundwater has been harvested. After this point, deeper boreholes and increased pumping will be required to harvest the remaining amount of water, potentially reducing the rate of production of water.

It is also possible that the production of water from the aquifer will continue to increase until all the economically affordable groundwater is harvested, after which the production of water drops quickly. In both these cases, the important point is that extraction will not fall to zero, but to the renewable recharge rate, where economically and physically sustainable pumping is possible.

"Peak Ecological Water"

For many watersheds, a more immediate and serious concern than "running out" of water is exceeding a point of water use that causes serious or irreversible ecological damage. Water provides many services: not only does it sustain human life and commercial and industrial activity, but it is also fundamental for the sustenance for animals, plants, habitats, and environmentally dependent livelihoods.

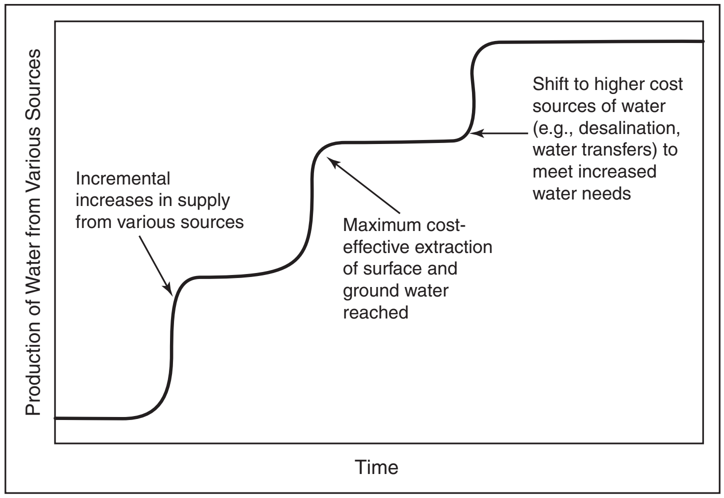

FIGURE 1.5 POTENTIAL WATER PRODUCTION SCENARIO IN A WATERSHED. This figure graphs a potential water production (supply) scenario in a watershed or region. As demand increases, incremental supply projects (dams, reservoirs, pumping) increase water availability. Once the maximum cost-effective extraction of surface and groundwater is reached, there is a final shift to a higher cost "backstop" supply of water such as desalination or water transfers.

Figure 1.5 graphs a potential water-production scenario in a watershed, where incremental supply increases through supply-side projects, e.g., groundwater harvesting, in-stream flow allocation, and reservoir construction are layered upon each other until the maximum cost-effective extraction of surface and ground water is reached. After this point, a final backstop supply of fresh water, such as desalination or water transfers, might be implemented.

Each new incremental supply project that captures water for human use and consumption decreases the availability of this water to support ecosystems and diminishes their capacity to provide services. The water that has been temporarily appropriated or moved was once sustaining habitats and terrestrial, avian, and aquatic plants and animals. As mentioned, by some estimates, humans already appropriate almost 50% of all renewable and accessible freshwater flows (Postel et al. 1996), leading to significant ecological disruptions. Since 1900, half of the world's wetlands have disappeared (Katz 2006). The number of freshwater species has decreased faster than the decline of species on land or in the sea. River deltas are increasingly deprived of flows due to upstream diversions, or receive water heavily contaminated with human and industrial wastes.

Figure 1.6 is a simplified graph of the value that humans obtain from water produced through incremental increases in supply (e.g., drinking water, irrigation), against the declining value of the ecological services (e.g., water for plants and animals) that were being satisfied with this water. The graph envisions that ecological services decrease as water is appropriated from watersheds. The pace or severity of ecological disruptions increases as increasing amounts of water are appropriated. Because ecological services are not well valued in dollar terms, the y-axis is labeled here simply as "value provided by water."

At a certain theoretical point, the value of ecological services provided by water is equivalent to the value of human services provided by water. After this point, increas-

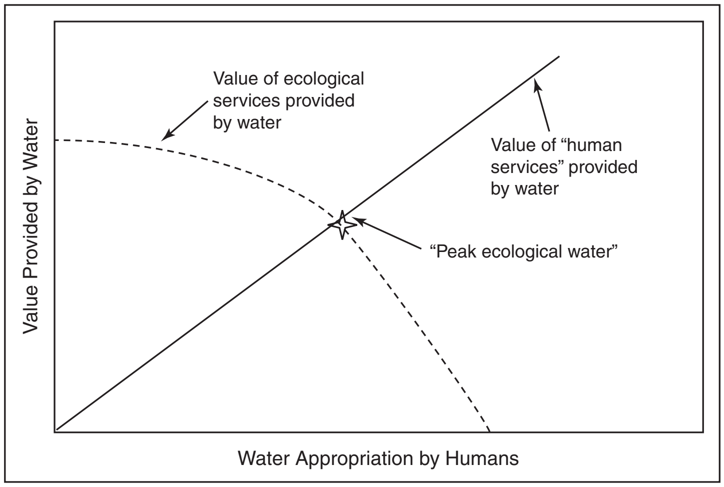

FIGURE 1.6 "PEAK ECOLOGICAL WATER": WHEN ECOLOGICAL DISRUPTIONS EXCEED THE BENEFITS OF NEW SUPPLY PROJECTS. Graph charts the value of water provided by increasing supply from various sources in a watershed against the loss in value of ecological services provided by this water. As water supply projects increase water production in a watershed (solid line), the ecological services provided by water are in decline (dashed line). At a certain subjectively determined point, the value of water provided through supply projects is equal to the value of the ecological services. Beyond this point ecological disruptions exceed the benefits of increased water extraction. We entitle this point "peak ecological water."

ing appropriation of water leads to ecological disruptions beyond the value that this increased water provides to humans (the slope of the decline in ecological services is greater than the slope of the increase in value to humans). At the point of "peak ecological water," society will maximize the ecological and human benefits provided by water. As shown in Figure 1.7, the overall value of water, combining ecological and social benefits, rises to a peak and then declines as human appropriation increases. Of

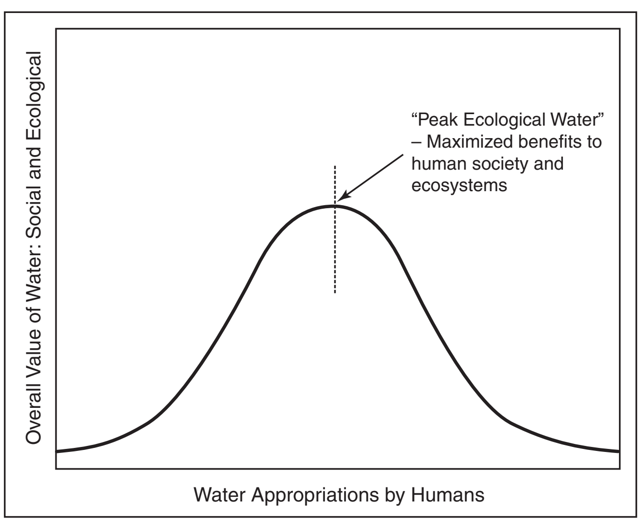

FIGURE 1.7 OVERALL VALUE OF WATER WITH INCREASING HUMAN APPROPRIATION OF WATER. Graph charts the overall value of water, a combination of social and ecological value, as water appropriation by humans increases. The value increases to a peak, where benefits to society and ecosystems is maximized, and then declines.

course, determining the point of "peak ecological water" is difficult to quantify and largely subjective based on different appraisals of the value of each unit of water in ecosystems and to humans.

Despite the difficulty in determining "peak ecological water," human societies make determinations as to what level of ecological disruption is acceptable to meet human needs (though they rarely do so with complete information about the true ecological consequences of their actions). The important point is that as human appropriations of water increase, there is a corresponding decrease in the ecological services this water can provide.

As human societies grapple with a water-constrained future, it is important to consider the many services that water provides. Whereas the use of the term "peak water" is flawed, the idea of maximizing both social and ecological benefits that water provides is more relevant. We propose the idea of "peak ecological water" as the point when maximum benefits to human society and the ecosystem can occur.

A New Water Paradigm: The Soft Path for Water

Real limits on oil production will, inevitably, stimulate efforts to identify and develop alternative energy sources capable of providing the same benefits as oil. And indeed, there are many substitutes for the different uses of oil for electricity, transportation fuels, lubricants, and the production of materials.

Real limits on water are far more worrisome, because water is fundamental for life, and for many uses, it has no substitutes. Absolute limits on affordable, accessible water will constrain the ability of regions to do certain things: in particular, limits to the availability of freshwater typically lead to the inability of a region to produce all the food required to meet domestic needs, and hence lead to a reliance on international markets for food. While this has been the subject of previous work in The World's Water (see, for example, "Water and Food" in the 2000–2001 volume, pp. 63–92), it is worth revisiting in the future. But limited water availability can also lead to more efficient use of water, better management of available resources, replacements with alternatives when possible, and increases in the resource productivity of water.

In the late 1970s, Amory Lovins coined the term the "soft path" for energy to denote an alternative approach for meeting human energy needs (Lovins 1977). The "soft path" recognizes that energy is a means to a certain end. People don't want energy itself, but transport, light, and warmth, as examples. The soft path for energy means reduction in wastage and inefficient use of energy, the deployment of renewable energy, and increased use of decentralized options, among other things.

Expanding this theme, Peter Gleick and others coined the concept of a "soft path for water" (Gleick 2002, 2003; Wolff and Gleick 2002; Brooks 2005). The "soft path" is a comprehensive approach to water management, planning, and use that uses water infrastructure, but combines it with improvements in the overall productivity of water use, the smart application of economics to encourage efficiency and equitable use, innovative new technologies, and the strong participation of communities and local water users in making decisions. Rather than seek endless sources of new supply, the soft path matches water services to the scale of the users' needs, and it takes environmental and social concerns into account to ensure that basic human needs and the needs of the natural world are both met.

A key insight behind the soft path for water is that people don't want to "use" water—they want to drink and bathe, produce goods and services, grow food, and meet human needs. Achieving this goal can be done the traditional "hard" way by building more dams, pipelines, and environmentally destructive infrastructure. Or, it can be done in a more integrated, sustainable, and effective way. The soft path can be distinguished from the traditional, hard path for water in six main ways:

1. **Focusing on ensuring water for human needs:** The soft path directs governments, companies, and individuals to meet the water needs of people and businesses, instead of just supplying water. People want clean clothes, or to be able to produce goods and services—they do not care how much water is used and may not care if water is used at all.
2. **Focusing on ensuring water for ecological needs:** The soft path recognizes that the health of our natural world and the activities that depend on it (like swimming, water purification, ecological habitat, and tourism) are important to water-users and people in general. The hard path, by not returning enough water to the natural world, ultimately harms human and other ecological users downstream.
3. **Matching the quality of water needed with the quality of water used:** The soft path leads to water systems that supply water of various qualities for different uses. For instance, storm runoff, gray water, and reclaimed wastewater are well suited to irrigate landscaping or for some industrial purposes that currently are supplied with more expensive potable water.
4. **Matching the scale of the infrastructure to the scale of the need:** The soft path for water recognizes that investing in decentralized infrastructure can be just as cost-effective as investing in large, centralized facilities. There is nothing inherently better about providing irrigation water from a massive reservoir instead of using decentralized rainwater capture and storage.
5. **Ensuring public participation in decisions over water:** The soft path requires water agencies, policy makers, or private entities to interact closely with water users and to engage community groups in water management. The hard path, governed by an engineering mentality, is accustomed to meeting generic needs with little transparency or public input.
6. **Using the power of smart economics:** The soft path recognizes the public and economic aspects of water, using the power of water economics to encourage equitable distribution and efficient use of water.

Conclusion

As the world anticipates a resource-constrained future, the specter of "peak oil"—a peaking in the production of oil—has been predicted. Similarly, many in the news media have begun referring to new limits on the availability of water, which some have termed "peak water." There are important differences between water resources and oil resources. Oil production will inevitably decline, while water uses within renewable limits can continue indefinitely. Oil is a finite, non-renewable resource that is consumed during its use; therefore, oil production will inevitably decline. Peak oil, thus, means the end of cheap, easy-to-access sources of petroleum. Any new sources of liquid fuel will be harder to reach and more expensive to extract. Water is a renewable resource and is not consumed in the global sense; therefore, water uses within renewable limits can continue indefinitely. Oil is routinely transported over long distances from extraction to use, making it a global resource. Conversely, water cannot be economically transported over long distances, making it primarily a local resource. These characteristics mean that there is a global limit to oil production; constraints on water are only manifested regionally. And while many water uses can be reduced or eliminated, a basic amount of water is necessary for life to exist and for which, unlike oil, there are no substitutes.

Despite the serious limitations in the concept of "peak water," as described in this chapter, there are some interesting and valid applications. Not all water use is renewable; indeed some water uses are non-renewable and unsustainable. Groundwater use beyond normal recharge rates follows a peak oil type curve with a peak and then precipitous decline in water production.

Considering the multiple roles that water provides as the fulcrum for ecosystems as well as human society, we suggest that the term "peak ecological water" better delineates an important crisis in the water sector. As human appropriation of water increases, the ecological services that water provides decrease. Once we begin appropriating more than "peak ecological water," ecological disruptions exceed the human benefit obtained. Defined this way, many regions of the world have already surpassed "peak ecological water"—humans use more water than the ecosystem can sustain without significant deterioration and degradation.

Another resonance in the concept of "peak water" is that similar to peak oil it signals the end of cheap and easy to access water. This recognition of the value of water can help drive towards an important and needed paradigm shift in the way water is managed and priced. In this way, the concept of "peak water" helps moves us towards using water in ways that improve the productivity, equity, and efficiency of water use.

What is exciting about the concept of "peak water" is that it may be an additional impetus for a new "soft path for water" paradigm to emerge. In places where peak water is a reality, managers are moving to recognize and manage water as a valuable and precious resource. True limits on regional water availability can also stimulate innovations and behaviors that can reduce water use and increase the productivity of water. Though the use of "peak water" is flawed in key ways, it shifts us in the direction of protecting and preserving precious water resources—a necessary step for a sustainable water future.

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