C H A P T E R 4

Fossil Fuels and Water Quality

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Fossil fuels are essential to the global economy—for electricity production, transportation, plastics and chemicals manufacturing, heating, and many other purposes. However, the extraction and processing of fossil fuels, in addition to their use, have profound impacts on the environment and natural resources, including water. Large oil spills—such as the recent Deepwater Horizon drilling rig spill, which leaked over 4.9 million barrels (780,000 cubic meters) of crude oil into the Gulf of Mexico—have focused attention on the potential for disasters associated with oil drilling to cause contamination of the natural environment (Lubchenco et al. 2010). The growing recognition of the serious risks to surface-water and groundwater quality from natural gas fracking operations also raises new questions. And even normal fossil-fuel extraction and refining processes pollute the environment.

The connections between water and energy have been studied in recent years, with growing recognition of how closely the two are linked. Water is used, in varying quantities and ways, in every step of fossil-fuel extraction and processing (Ptacek et al. 2004). For example, the amount of coal produced worldwide in 2009 required an estimated 1.3 to 4.5 billion cubic meters (m^3) of water for extraction and processing.[1] Oil refining requires approximately 4 to 8 million m^3 of water *daily* in the United States alone (the amount of water that two to three million U.S. households use daily) (US DOE 2006). But while interest has grown in the volume of water required for energy production, the water-quality impacts have been given much less attention.

Because water is used in so many ways during fossil-fuel extraction and processing (see Table 4.1), there are also many ways in which it can become contaminated with a wide variety of pollutants, from sediment to synthetic chemicals. Additionally, nearby water bodies and groundwater may become contaminated by solid or liquid wastes created by the extraction process. Mining and drilling for fossil fuels bring to the surface materials long buried in the Earth, including water, and generate large quantities of waste materials or by-products, creating large-scale waste disposal challenges. Water brought to the surface through mining or drilling, called "produced water," can contain dissolved salts, trace metals, hydrocarbons, and radionuclides (USGS 2010). Spills and other disasters associated with the extraction process, such as the spill of over one million m^3 of coal slurry in Kentucky in 2000 when a containment dam failed, are another source of contamination (US DOE 2006). Finally, surface water may drain into mine openings, and groundwater frequently accumulates in mines, leading to the creation

1. Based on estimated water use for underground mining plus beneficiation from Gleick 1994 (7 m^3 to 24 m^3 of water per 10^{12} joules) and EIA coal production data. Energy contained in 1 metric ton of coal is assumed to be 27 *10^9 joules.

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Table 4.1 Connections Between Water and Fossil-Fuel Extraction and Processing

	Process	Connection to Water Quality	Connection to Water Quantity
Energy Extraction & Production	**Oil and gas exploration**	Impact on shallow groundwater quality	Water for drilling, completion, and fracturing
	Oil and gas production	Produced water can affect surface and groundwater	Large volume of produced, impaired water
	Coal and uranium mining	Tailings and drainage can affect surface water and groundwater	Mining operations can generate large quantities of water
Refining & Processing	**Traditional oil and gas refining**	End use can affect water quality	Water needed to refine oil and gas
	Biofuels and ethanol	Refinery wastewater treatment	Water for growing and refining
	Synfuels and hydrogen	Wastewater treatment	Water for synthesis or steam reforming

Source: Modified from US DOE 2006.

and possible release of acid mine waters. These impacts can make water unsuitable for other purposes, such as supporting ecosystems or domestic human uses, and in some cases degradation continues for decades or centuries after the fuel is extracted. While the total volume of water contaminated by fossil-fuel production is not known, widespread cases of contamination indicate that it poses a significant, large-scale water-quality problem.

Fossil-Fuel Production and Associated Water Use

Fossil fuels are produced, in varying quantities, in every major region of the world (see Table 4.2). The water-related impacts of fossil-fuel extraction and refining in a given region are a function of multiple factors, including the amount and type of fossil fuel produced, the extraction methods used, physical and geological conditions, and regulatory requirements (Mielke et al. 2010). In some cases, social conditions such as political stability also influence the links between water and energy. In Nigeria, for example, political corruption and social tensions have contributed to a high incidence of oil spills because oil companies are often not held accountable for polluting, and because of vandalism of oil pipelines.

At the global scale, 22 percent of all water used is for industrial purposes, including mining and fossil-fuel extraction and power generation (UN WWAP n.d.). Estimates for the amount of water used globally specifically for fossil-fuel extraction are not well developed, and many are based on water-intensity estimates from one article (Gleick 1994) that is over 15 years old. Data on the water-quality impacts of fossil-fuel extraction and processing are even more poorly developed than those on water quantity and in many cases are not available at all, as water quality is not well monitored in many regions of the world.

One estimate for global water use for oil production, produced by applying water intensities per unit of oil extracted to global oil production figures, puts total water use at 13 billion m^3 of water for oil production worldwide in 2006 (Maheu 2009). This estimate takes into account the differing water intensities of oil produced in different

Table 4.2 Top Ten Fossil Fuel–Producing Countries (2008)

	Total Oil Supply			Dry Natural Gas			Primary Coal Production		
Rank	Country	Thousand Barrels /Day	% of world	Country	Thousand Cubic Feet	% of world	Country	Thousand Short Tons	% of world
1	Saudi Arabia	10,782.1	13%	Russia	23,385.6	21%	China	2,847,983.4	39%
2	Russia	9,792.3	11%	United States	20,377.0	19%	United States	1,171,808.7	16%
3	United States	8,514.2	10%	Canada	6,036.6	5%	India	568,323.1	8%
4	Iran	4,175.4	5%	Iran	4,107.1	4%	Australia	438,506.1	6%
5	China	3,982.7	5%	Norway	3,503.2	3%	Russia	356,185.5	5%
6	Canada	3,331.6	4%	Algeria	3,054.9	3%	Indonesia	313,231.7	4%
7	Mexico	3,186.7	4%	Netherlands	2,990.9	3%	South Africa	259,596.5	4%
8	United Arab Emirates	3,050.0	4%	Saudi Arabia	2,840.7	3%	Germany	214,351.1	3%
9	Kuwait	2,726.2	3%	Qatar	2,718.6	2%	Poland	157,881.9	2%
10	Venezuela	2,639.7	3%	China	2,685.4	2%	Kazakhstan	119,808.0	2%
	World	**85,459.7**		**World**	**109,788.5**		**World**	**7,271,748.6**	

Source: US EIA 2010a.

Table 4.3 Typical Energy Content of Fossil Fuels and Unit Conversions

Fossil Fuel	Typical Energy Content
Petroleum	6.1 gigajoules per barrel (GJ/bbl)
Natural Gas	1.1 megajoules per cubic foot (MJ/ft^3)
Coal	26 gigajoules per metric ton (GJ/te)
Tar Sands	6.1 GJ/bbl
Oil Shale	6.1 GJ/bbl

Unit Conversions
1 barrel (bbl) = 42 gallons = 0.159 cubic meters (m^3)
1 cubic foot (ft^3) = 0.0283 m^3
1 British Thermal Unit (Btu) = 1055 joules

regions and with different extraction techniques. As noted previously, global coal production in 2009 required an estimated 1.3 to 4.5 billion m^3 of water for extraction and processing. Global production of natural gas in 2009 required an estimated 840 million m^3 of water.[2] This water use is attributed exclusively to processing of natural gas since traditional extraction methods require negligible quantities of water. However, with the increasing use of hydraulic fracturing (often called "fracking,") water use and water-quality impacts related to natural gas extraction are likely to increase greatly. While these coal and natural gas estimates do not take into account differences in the water intensity of extraction between regions, they provide a rough approximation. Table 4.3 offers the typical energy content of fossil fuels for different reporting units along with unit conversions.

2. Based on water use data in Gleick 1994 (6 m^3 of water per 10^{12} joules) and EIA natural gas production data. Energy contained in 1 trillion cubic feet (TCF) of natural gas is assumed to be 1.05 * 10^{18} joules.

Fossil Fuels and Water Quality: Direct Impacts

Petroleum

From extraction to end use, petroleum products affect surface water and groundwater, impairing water quality with hydrocarbons, salts, nutrients, a host of organic compounds, and various heavy metals. In many areas around the world, oil spills and stormwater runoff containing oil derivatives have degraded ecosystems and human water supply.

Petroleum, also known as crude oil, comes from the remains of prehistoric life subjected to heat and pressure for millions of years. Over time, petroleum accumulated in oil fields, between layers of impermeable rock. Crude oil is extracted from these fields through a series of recovery methods that run from tapping into the fields' initial pressure (known as primary recovery) to pressurizing the fields with water or steam or other gases to force the oil to the surface (known as secondary and tertiary, or enhanced, recovery). Total daily global crude oil production (extraction) runs about 85 million barrels, equivalent to about 12 million metric tons (US EIA 2010a). In 2009, Russia accounted for 12.9 percent of total global production, followed by Saudi Arabia at 12 percent, the U.S. at 8.5 percent, Iran at 5.3 percent, and China at 4.9 percent (see Table 4.2 for 2008 production values) (BP 2010). In the United States, about one-quarter of domestic production comes from offshore wells, but global offshore oil production is only about 6 percent of total global production. Producers convey crude oil from the well via pipelines or ships to refineries, where crude oil is distilled into a variety of petroleum products, including gasoline, kerosene, fuel oils, liquefied petroleum gas, various lubricants, asphalt, and precursors to plastic and pharmaceutical products, among others. These petroleum products are then distributed via various modes to other manufacturers and to end users.

Each of these steps requires or can affect water. Oil fields themselves usually contain large volumes of salty water. The water that comes to the surface along with extracted crude oil is known as produced water. Produced water can contain hydrocarbon residues, heavy metals, hydrogen sulfide, and boron, as well as elevated concentrations of salts. The ratio of produced water to crude oil tends to rise with the age of the well. Khatib and Verbeek (2003) estimated that oil production generates roughly three times as much produced water as crude oil, equivalent to about 15 billion m^3 of produced water annually worldwide. Historically, producers disposed of this waste stream with direct disposal into the environment or into evaporation pits that were often little more than holes in the ground that allowed produced water to infiltrate into local aquifers and contaminate groundwater sources or streams fed by these aquifers (Pettyjohn 1971). Khatib and Verbeek (2003) estimated that about 55 percent of one major oil company's produced water was re-injected into the ground. Clark and Veil (2009) found that some 98 percent of produced water from onshore wells in the United States was re-injected but that 91 percent of produced water from offshore wells was simply discharged into the ocean. Assuming that the 2 percent rate of U.S. onshore-produced water that is not re-injected can be applied globally—probably an optimistic assessment—yields an annual worldwide total of 300 million m^3 of produced water remaining on the surface.

The large volumes of produced water are the greatest single connection between oil production and water quality, but each step of the oil extraction and refining process has led to contamination of water resources. Oil spills from wells are not uncommon and can pollute vast areas both offshore and onshore, generating clear and measurable environmental impacts. Spills during the conveyance of crude oil from the point of extraction to refineries also occur with some regularity. The Exxon Valdez oil tanker spill, which garnered significant public attention, is only one example of many and in fact does not rank among the top 25 largest oil spills worldwide (O'Rourke and Connolly 2003). In Nigeria, an estimated 260,000 barrels of oil (41,000 m^3) spill each year into the Niger Delta and surrounding areas, with devastating impacts on people, plants, and wildlife (Vidal 2010, Nassiter 2010). Marine spills such as these can lead to freshwater system contamination when the oil hits the shoreline and drifts up through estuaries into streams. In the U.S., spills into freshwater systems occur more frequently than marine spills; between 1995 and 1996, 77 percent of all spills greater than 1,000 gallons and 88 percent of spills greater than 10,000 gallon were inland spills. The majority of these spills were from oil pipelines (Yoshioka and Carpenter 2002).

After production, crude oil is refined through a series of water-intensive processes: water is used for steam, as part of the refining process, as wash water, and for cooling. Process water typically becomes contaminated with sulfur and ammonia, requiring treatment. Cooling system water has little direct contact with petroleum products, though trace contaminants may appear in cooling system water. Such cooling water is the largest consumptive water use in refining, at a rate of three to four units of cooling water per unit of crude oil, depending on the type of cooling system. Because of the large volumes of water required for operation, refineries are often located adjacent to water sources. The sheer size of many refineries—often covering square kilometers of land—means that, in some countries, precipitation on the refinery grounds must be captured and treated so as not to contaminate adjacent water bodies.

Refined petroleum products continue to affect water quality, though their impacts typically become more diffuse once the products are refined and distributed. In the United States, the Environmental Protection Agency has recorded more than 490,000 confirmed leaks from underground storage tanks (USTs), which are generally used to store petroleum products. As of March 2010, there were more than 600,000 active USTs and more than 1,734,000 closed USTs in the country (US EPA 2010). The total number of USTs worldwide is not known. Leaking USTs can contaminate groundwater resources with gasoline, diesel fuel, and related compounds, such as benzene and toluene. The total volumes leaked from USTs, and the total volume of groundwater affected by such leaks, is not known.

In the U.S., more than 75 percent of refined petroleum becomes gasoline, diesel, and jet fuel (Teufel and Azelton 2008). The distribution and combustion of these fuels also affect surface water and groundwater. Once the refined gasoline and diesel fuels reach motor vehicles, spills and combustion by-products can become non-point sources of pollution, washed by stormwater runoff into streams or infiltrating into groundwater. Combustion of these fuels discharges nitrogen and other contaminants to the atmosphere, which in turn can be carried back to the earth in precipitation, increasing pollution loadings to lakes and streams. Incompletely combusted fuels and minor spills and leaks from motor vehicles also generate contaminants. One study found that runoff from one square kilometer of roads and parking lots carried the equivalent of more than 180 barrels of oil annually (NRDC 2001). Although there do not appear to be any estimates of the total volume or impacts of such end-use impacts on even a local scale, much less any global estimates, extrapolating from this one estimate suggests that stormwater runoff carries the equivalent of almost 20 million barrels of oil (more than 3 million m^3) annually nationwide (about 0.8 percent of total annual motor fuel consumption), though this should be considered little more than an order of magnitude estimate. Total global runoff from contaminated surfaces could not be estimated from available data.

Unconventional Petroleum

Unconventional petroleum, which includes tar sands and oil shale, is not extracted with conventional wells. Unconventional petroleum requires more complex extraction and processing than does crude oil, and its water-quality impacts are potentially many times greater than those of conventional crude.

Tar Sands

Tar sands, sometimes known as oil sands, are a mix of clay, sand, water, and bitumen. Bitumen is a thick, tarlike substance that can be processed into "synthetic crude," which can then be further processed by an oil refinery. Bitumen is also used directly in asphalt and other applications. Almost half of Canada's total oil production comes from the Alberta tar sands, equivalent to about 1.5 million barrels of oil per day, or 86.4 million m^3 total in 2009 (Gosselin et al. 2010). The total recoverable oil equivalent in Alberta's tar sands may exceed 27 billion m^3, second only to Saudi Arabia's oil reserves (Gosselin et al. 2010). Venezuela has a small commercial tar sands operation, and small deposits have been found in the Middle East. In eastern Utah, in the U.S., a controversial effort to develop tar sands is now under way (WRA 2010). Tar sands production is more complicated and capital intensive than typical petroleum production. Companies extract bitumen either via surface mining or in situ, which typically involves injecting steam into the tar sands deposits to decrease bitumen's viscosity and enable it to flow into pools, where it can be extracted.

Tar sands mining operations use large volumes of water to separate the bitumen from parent materials. Roughly two-and-a-half units of water are required to extract and process one unit of bitumen by surface mining, yielding an annual water-use volume of roughly 100 million m^3 (Gosselin et al. 2010). This processing water, as well as water released from the tar sands as the bitumen is refined, and water produced by the formations themselves, contains high concentrations of hydrocarbons and other contaminants and must be treated or contained. The large volumes of material mined from the surface to extract bitumen—as much as two tons of tar sands per barrel of oil—generates massive volumes of waste materials, which can then leach hydrocarbons, heavy metals, arsenic, selenium, and other hazardous materials into surrounding waterways. Typically, tailings are mounded to create retaining ponds for contaminated water.

Oil Shale

For the past 100 years, oil shale has periodically been promoted as the fuel of the future—a future that has never been realized. Despite federal and private investments of hundreds of millions of dollars, research and development efforts have yielded limited results. Commercial development remains a distant goal. In the United States, the federal government is again trying to jumpstart this nascent industry. Oil shale deposits are found worldwide, with some of the richest formations located in the Green River

Formation underlying Colorado, Utah, and Wyoming (US BLM 2008). A fundamental problem with developing these oil shale deposits is the thermodynamics of the resource. There is no oil in oil shale. Instead, the shale rocks contain kerogen, a waxy substance that liquefies when heated, producing a precursor to crude oil. Kerogen must be further processed and refined before it is suitable for use as transportation fuel. Extraction and refining will both require large quantities of energy and water, though, to date, the actual amounts of energy and water required have not been determined.

There are two primary methods to extract kerogen, neither of which has proven commercially viable: mining and retort, and in situ. Mining and retort requires mining the shale, crushing it, and heating the rock to separate the kerogen. This requires huge quantities of energy and water. There are various technologies under development for in situ extraction. One such process requires heating the shale rock in place to 370°C for three years and using wells to extract the kerogen. Another in situ method being explored is separating the kerogen via chemical processes.

Of the many anticipated environmental impacts from oil shale, perhaps the most serious are impacts to water quality. Mining operations, such as retort operations proposed for Utah, would leave large piles of spent shale, which could leach hydrocarbons, salts, trace metals, or other minerals, including nitrate, arsenic, boron, barium, iron, lead, selenium, and strontium, into surface-water and groundwater supplies (US BLM 2008, WRA 2010). Further, water extracted during processing may also be filled with metals and organic materials that can significantly degrade water quality in the region (US BLM 2008). Development would also disturb soils and ground surfaces, thereby increasing rates of erosion and the amount of sediment washed into streams and rivers. Traffic on rural, dirt access roads would add to this problem (US BLM 2008). Oil shale extraction could generate large quantities of produced water that must be re-injected or held in retention ponds, where it could leak or otherwise contaminate surface water and groundwater. Some oil shale processing methods use alkaline water that could mobilize toxic materials such as arsenic and selenium (Hanson and Limerick 2009).

Natural Gas

Like petroleum, natural gas comes from organic matter subjected to intense heat and pressure for millions of years. Natural gas can be produced from dedicated wells or coproduced with oil from oil wells. Most commonly, wells permit natural gas to flow to the surface naturally; however, in some geologic conditions, lifting equipment, such as rod-pumping, is required (Natural Gas Supply Association n.d.). In the U.S., roughly 22 percent of natural gas production comes from oil wells and the remainder from dedicated gas wells, including roughly 8 percent from coalbed methane (see the following section) (U.S. DOE 2010c). According to BP (2010), total global natural gas production in 2009 was 2.987 trillion m^3 (289 billion cubic feet), a decline of 2.1 percent from 2008. In 2009, the U.S. produced 20.1 percent of total global production, Russia produced 17.6 percent, Canada produced 5.4 percent, and Iran produced 4.4 percent. Table 4.4 shows natural gas consumption by end use in the U.S. in 2009. About a third of total U.S. consumption goes to electricity generation and the rest to a range of commercial, industrial, and residential purposes; end uses at the global scale were not available.

Natural gas production degrades water quality primarily at the extraction stage, though processing and combustion also affect water quality to lesser degrees. Like

Table 4.4 U.S. Natural Gas Consumption by End Use (2009)

End Use	Percent of Total
Electrical Power Generation	30.3
Industrial	26.8
Residential	20.8
Commercial	13.6
Production, Processing, and Distribution	8.3

Source: US EIA 2010b.

petroleum, natural gas extraction can generate large volumes of produced water, often contaminated by hydrocarbon residues, heavy metals, hydrogen sulfide, and boron, as well as elevated concentrations of salts. Clark and Veil (2009) report that gas extraction generates about one-sixth as much produced water as petroleum extraction, at an average rate of 182 barrels of water per million cubic feet of production. Extrapolating from this figure yields an estimated three billion m^3 of produced water globally from natural gas extraction each year. In the U.S., most produced water from traditional onshore operations is re-injected; the fate of such water globally is not known.

Methane is the main compound of natural gas as used by consumers, but natural gas deposits contain a mixture of other compounds that must be removed before the methane is suitable for use by the consumer. Once extracted, gas undergoes initial processing near the wellhead. The gas is then transported, typically via pipeline, to a processing plant for further purification, to separate methane from other compounds in the raw natural gas, including propane, butane, water vapor, hydrogen sulfide, and carbon dioxide. Some of these, such as propane and butane, have commercial value. Water, hydrogen sulfide, and other compounds must be removed and treated or retained by the processing plant, to avoid environmental contamination. The purified natural gas is then delivered to end users, again typically via pipeline, though in remote areas it is often cooled and transported via tankers as liquid natural gas.

Burning natural gas leaves negligible solid waste and generates far fewer particulates than burning coal or petroleum. Like all fossil fuels, natural gas combustion generates carbon dioxide and nitrogen oxides, though at markedly lower rates than coal combustion. Methane itself is also a greenhouse gas, contributing to the heat-trapping capacity of the atmosphere, and like carbon dioxide, its concentration has risen dramatically in the past century. Per unit mass, methane traps more than 20 times as much heat as carbon dioxide, though the volumes of methane emissions are a very small fraction of total carbon emissions and methane has a shorter life span in the atmosphere. Still, methane from all sources contributed more than 10 percent of total greenhouse gas emissions in the U.S. in 2008, as measured by carbon equivalents.

Unconventional Natural Gas

The three basic forms of unconventional natural gas reservoirs are coalbed methane, tight natural gas, and shale gas. Unlike conventional natural gas, these unconventional forms are trapped in rock with very low permeability and therefore typically require stimulation in order for the gas to be extracted. Because unconventional natural gas has not been economical to extract, the extent of global resources has not been fully assessed. However, the amount of these types of gas produced are likely to increase substantially, particularly in the U.S., Canada, and China (US EIA 2010b), as conventional gas resources get more difficult and expensive to reach.

Hydraulic fracturing or fractionation, also known as fracking, is a method used to increase production of these types of natural gas wells, especially gas shales. The process forces liquids under high pressure into rock formations surrounding gas deposits, breaking up the rock and releasing the gas for capture by the well. The liquid used for fracking contains sand, to prop open the fractures, and a number of chemical additives, whose compositions are rarely disclosed to the public or regulators. Although the process was developed in the 1970s and 1980s, it is only recently emerging as a widely used recovery technique and is becoming increasingly controversial as new evidence of environmental contamination and groundwater problems emerges. It was originally used almost exclusively in North America and to some extent in Germany, primarily because it was not an economical extraction method in other areas. However, it is now in use or is planned to be used in a variety of regions, including India, the United Kingdom, and China. Fracking has dramatically increased natural gas production and has facilitated production in many areas previously considered uneconomical, but this expansion in the number of wells, and especially fracking itself, raises the scope and severity of water contamination. Fracking is a water-intensive process—each well requires two to five million gallons of water (GWPC and ALL Consulting 2009; US EPA 2010). Disposal of the recovered fracturing fluid, and the unknown amount and composition of fluid that is not recovered, could contaminate groundwater and surface-water bodies.

Shale Gas

Shale gas is trapped in the pore space of shale rocks, which have extremely small pore sizes compared to the rocks in which conventional gas is trapped. This makes them impermeable to gas flow, and they therefore require natural or artificial fractures in the rock to release the gas (Andrews et al. 2009). Shale gas wells are often drilled horizontally, and most are hydraulically fractured (GWPC and ALL Consulting 2009).

Tight Gas

Tight gas is found in low-porosity sandstones and carbonate reservoirs. Like shale gas, the relatively impermeable nature of the rock in which tight gas is found means that it generally requires hydraulic fracturing or acidizing in order to release the gas (GWPC and ALL Consulting 2009).

Coalbed Methane

Coalbed methane, or CBM, is sourced from within a coal seam or in the surrounding rock. Major CBM deposits are found in Australia, Canada, and the United States, with smaller deposits in England and South Africa. CBM is loosely bound to coal and is typically held in place by the pressure of water in the coal deposits. CBM extraction requires removing water from the coal bed, thereby decreasing pressure on the gas and allowing it to flow up the well. The extraction process can alter groundwater levels, including by decreasing pressure in local wells and, in cases where the groundwater is shallow, in surface flows. Water-quality impacts due to extraction include methane leaks (with impacts on vegetation and, in some cases, explosions), strong odors, and cloudy or slimy well water.

In some areas (e.g., the Powder River Basin in the U.S.), produced water from coal beds is discharged to the surface, where it can concentrate salts and other substances in the soil, affect land productivity, and alter water quality, including temperature. In other areas (e.g., the San Juan Basin), produced water is typically re-injected (usually into geologic formations that lie below the aquifer from which the CBM is produced). Some propose that produced water might, after proper treatment, be discharged into surface streams to help offset decreased flows due to other diversions or even climate change. A key problem with this approach is that produced water is a finite supply that would be only a temporary, stop-gap measure to address a much longer term problem.

Coal

Like petroleum and natural gas, coal comes from organic matter subjected to intense heat and pressure for millions of years. Coal, however, is a solid—a sedimentary rock—extracted through surface and underground mining. According to the U.S. Energy Information Administration (U.S. EIA), total global coal production and consumption in 2009 was about seven billion metric tons. China produced 44 percent of this amount, followed by the United States at 14 percent and India at 8 percent. In the U.S., more than 90 percent of coal consumption is used to generate electricity, producing roughly half of all electricity generated in the country. Some forms of low-sulfur coal are baked at extremely high temperatures to make coke, which is used in the production of steel. Coal is also used for cement and aluminum manufacturing, and coal by-products are used to produce fertilizers and various plastics, among other products. U.S. EIA reports that coal combustion generated 36.5 percent of the United States' annual total greenhouse gas emissions in 2008. Coal generates more carbon dioxide per unit energy than petroleum, but petroleum constituted 44.6 percent of total fossil-fuel energy production in 2008, compared to coal's 26.8 percent (US EIA 2008).

Water is used throughout coal production, from extraction to processing, and occasionally for transportation. Water is used for cooling and cutting in the mines, for suppressing dust, for irrigating as part of land reclamation efforts, and for washing coal to remove sulfur, mercury, and other impurities. Mielke et al. (2010) report the consumptive use of water for coal mining and washing at 1 to 8 gallons/MMBtu in the U.S., roughly equivalent to 80 to 650 million m^3 per year in the U.S., depending on the thermal energy per unit coal. These estimates are very dated and might not be accurate: Mielke et al. (2010) and Younos et al. (2009), among other recent reports on volumes of water embedded in energy production, cite the U.S. Department of Energy (US DOE 2006), which in turn cites Gleick (1994), who cites data from the 1970s and 1980s. Thus, current estimates are based on research that is more than 20 years old, and in some cases more than 30.

According to one estimate that converted water use per unit of energy to water use per unit of mass by calculating from a range of energy equivalents per ton of coal, from 800 to 3,000 gallons of water are used for the extraction, processing, transport, and mitigation (such as land reclamation efforts) of one short ton of coal (K. Schneider, pers. comm.). Extrapolating from these volumes suggests that on the order of 20 to 90 billion m^3 of water are used annually for coal production processes worldwide. Gleick (1994) commented on the absence of good estimates on the amount of water contaminated by coal production; nor does there appear to have been any good estimates since then.

Although volumes of water contaminated by coal production are not known, it is clear that extraction, processing, and transportation of coal and related production materials can adversely impact surface-water and groundwater quality at each step of production and use.

When coal seams lie within about 60 meters of the surface, coal is extracted using various methods of surface mining, including strip mining, mountaintop removal, and open pit mining. Surface mining typically employs massive machines or explosives to remove the "overburden"—a euphemism for the soil, vegetation, animals, and functioning ecosystems—covering the coal seam. The volume of overburden varies dramatically by region and is a key factor determining the economic productivity of the mine; Gupta (2000) reports that the ratio of overburden to coal can range from 5:1 to 27:1. In some cases, the overburden is subsequently used to fill the hole left by surface mining operations, though in other cases, especially in mountaintop removal, it is dumped into valleys, burying and blocking streams. Surface mining generally—and mountaintop removal in particular—denudes the landscapes and compacts soils, increasing runoff rates and decreasing infiltration and groundwater recharge. Palmer et al. (2010) found a number of water-quality impacts in streams affected by mountaintop removal mining, including increases in alkalinity, electrical conductivity, heavy metals, and concentrations of sulfates and other ions, as well as decreased biodiversity.

According to the World Coal Association, surface mining accounts for roughly two-thirds of U.S. coal production but only about 40 percent of global coal production; the remainder comes from underground mining. Various methods are used to extract coal from underground mines, often using sophisticated machines and monitoring equipment. Although underground mining generates less spoil material than surface mining, these mine spoils often include heavy metals, sulfurous compounds, and other materials that leach into surrounding watercourses, often generating acid mine drainage that disrupts ecological functions (as described below).

Miners move extracted coal to processing plants, often located near the mine location. Processing requirements vary markedly by location and type of coal. Coal in the eastern U.S. and in some other areas typically contains higher sulfur concentrations. Processing plants clean the coal, removing some of the impurities and extraneous materials. Some methods use large volumes of water to wash the coal, decreasing concentrations of sulfur, mercury, and other contaminants in the coal but increasing them in the wastewater. Coal-processing wastewater can be discharged into underground mines or may be discharged into surface holding ponds. Both can degrade water resources, contaminating groundwater or leaking into surface-water bodies. Retention ponds have failed on occasion, releasing large volumes of polluted water downstream, sometimes with catastrophic impacts. For example, a 29-hectare retention pond in Kentucky, U.S., failed in October 2000, releasing almost a million cubic meters of coal-processing wastewater into a nearby mine. The contaminated wastewater then drained into nearby streams, causing flooding to a depth of almost two meters, disrupting local water supplies, and causing extensive environmental damage (National Research Council 2002). One website lists 66 separate coal impoundment spills in the eastern U.S. in the years 1972–2008 (CILIS n.d.).

After processing, coal is often transported via rail or barge to the point of consumption. In one location, crushed coal was mixed with water to form a slurry and then conveyed 440 kilometers (km) via pipeline to a power plant, though this plant has since been closed. Transportation accidents and related coal spills tend to be easier to contain than spills of liquid petroleum, though spills into waterways can leach harmful materials, such as mercury, sulfur compounds, arsenic, and lead.

Most coal moves from the mine to a power plant, where it is crushed and burned to generate electricity. Combustion residues, known as coal ash, are composed of airborne particulates known as fly ash and residual materials known as bottom ash. In some countries, fly ash is now captured; some is used in the production of concrete, while the remainder is mixed with bottom ash and disposed of in landfills or stored wet in retention facilities, to minimize dust emissions. On December 22, 2008, a wet coal ash holding pond failed in Tennessee, U.S., spilling some 3.7 million m^3 of wet coal ash into the Emory River. A medium-term study of the spill impacts found high arsenic concentrations in downstream waterways, especially in protected areas with limited flows and in bottom sediments (Ruhl et al. 2010). Other users of coal products can also degrade surface-water and groundwater resources; for example, in Brazil recently, steel manufacturers were fined for discharging toxic coal residues directly into waterways (AP 2010).

Impacts on Freshwater Ecosystems

Freshwater ecosystems are affected in a variety of ways by the direct impacts of fossil-fuel extraction and mining outlined earlier. These ecosystem impacts fall into four basic categories: (1) impacts related to climate change, (2) physical impacts, (3) chemical impacts, and (4) biological impacts.

Climate Change

Fossil-fuel production and combustion generates some 90 percent of total U.S. greenhouse gas emissions; lower fossil-fuel use rates and higher rates of land-use changes in other parts of the world suggest that fossil fuels contribute a slightly lower, though still disproportionately large, share of global greenhouse gas emissions. These emissions are already changing the global climate, including temperature and precipitation, and risk dramatically altering the hydrologic cycle. The extraction and use of carbon-intensive fossil fuels generates fundamental changes in the global distribution of water, in turn affecting a host of water-quality parameters, including sedimentation, temperature, and dissolved oxygen concentrations (Fischlin et al. 2007). Projected increases in storm intensity will amplify runoff from contaminated surfaces, both in urban areas and from tailings piles, and could overwhelm efforts to retain and manage such contaminated runoff. Increased storm intensity could also affect coal ash and other retention ponds, increasing the risk of pond failure and subsequent release of contaminated materials into downstream waterways.

Decisions about current and future energy supplies present critical opportunities. Retiring aging thermoelectric power plants may create "new" water supplies that can meet growing urban demands or environmental needs while reducing greenhouse gas emissions, if their generation capacity can be offset through energy-efficiency improvements or less water-intensive energy sources. For example, recent legislation in Colorado directed Xcel Energy to replace 900 megawatts of coal-fired power plants in the Denver metropolitan region with natural gas units, energy efficiency, and other resources. This legislation will provide important (though incidental) benefits to water resources. As other plants near the end of their design life span, additional opportunities for advancing an integrated energy, climate, and water policy may arise.

Physical Impacts

Fossil-fuel production and use can create a variety of physical changes in water resources, including changes in channel structure, sediment-transport dynamics, groundwater–surface water connectivity, and subsurface water connectivity and mobility, as well as temperature changes in surface and groundwater. The most dramatic change in channel structure comes from the surface-mining method known as mountaintop removal and valley fill, in which streams are completely buried by tailings, as described earlier. Figure 4.1 shows a mining and valley fill operation in West Virginia, U.S., in 2009. Underground coal mines and surface-mining operations for coal and tar sands all generate large volumes of tailings that can wash into and choke streams, burying fish eggs and aquatic insects. Fracking can also increase groundwater mobility, connecting pockets of highly saline or otherwise contaminated groundwater with drinking-water wells and alluvial aquifers, permitting the migration of hydrocarbons, benzene, arsenic, and other contaminants into drinking water supplies and into surface waterways. Similarly, in situ methods for extracting petroleum and tar sands, such as the injection of steam or lubricants and surfactants, can increase the mobility of underground contaminants and contaminate groundwater resources. Thermal pollution occurs at a much larger scale at power plants burning fossil fuels, where cooling water absorbs excess heat from the plant and is then discharged into streams or lakes, typically increasing the chemical and biological oxygen demand in the receiving water.

Figure 4.1 Sediment Ponds, Valley Fill, and Edge of Coal Mine near Bob White, West Virginia, United States.

Source: Vivian Stockman, http://www.ohvec.org

Chemical Impacts

At every stage of their production and use, fossil fuels can create a host of adverse chemical impacts on water quality. Fossil-fuel production, transmission, and use can contaminate water resources with hydrocarbons, heavy metals, increased nutrient and salt loads, and a host of toxic compounds, including benzene, toluene, and hexavalent chromium. The ubiquity of pipelines and tanker trucks, not to mention personal and commercial vehicles, makes fuel leaks and spills a statistical certainty, as noted earlier. Coal mine tailings often leach heavy metals and acids into nearby streams, dramatically lowering pH (often to levels of 2 to 3) and decimating or even extirpating entire aquatic communities (Swer and Singh 2004). Abandoned mines themselves, common throughout many areas of the world, pose their own long-term threats to water quality: such mines often contain heavy metals and sulfur compounds and can fill and spill from surface precipitation and groundwater, generating acid mine drainage (Banks et al. 1997).

Produced water from oil, gas, and coal extraction typically contains hydrocarbon residues, heavy metals, hydrogen sulfide, and boron, as well as elevated concentrations of salts. Although most produced water is re-injected or discharged to the ocean, more than 300 million m^3 per year of such water stays on the planet's surface, stored in retention ponds or discharged generally to the land or water, where it can contaminate groundwater and surface-water resources. Processing and refining fossil fuels also generate chemical wastes that, if not properly managed, can contaminate water with petroleum wastes, heavy metals, selenium, and other contaminants. In 2008, a Texas petroleum refinery was fined for more than 2,000 unlawful discharges between 1999 and 2006 ("Refinery Water Pollution" 2008). Combustion of coal and petroleum products generates large quantities of sulfur and nitrous oxides that can generate acid precipitation and excess nutrient loadings on land and water surfaces. Coal combustion leaves coal ash, which is often stored wet in retention ponds, though such ponds have failed, discharging selenium, arsenic, and other contaminants into nearby streams. Fuel spills from personal and commercial vehicles are widespread, leaving residues on impervious surfaces that can wash into streams or lakes or percolate into the ground after precipitation events.

Ecological Impacts

Many aspects of fossil-fuel production directly affect aquatic resources and can cause mortality events or otherwise degrade ecological resilience. At the global level, the clear link between fossil-fuel combustion and climate change means that the ecological impacts of climate change can be largely attributed to fossil fuels. The scientific literature robustly describes the intersection of climate change, water quality, and ecosystems (see Fischlin et al. 2007, Meyer et al. 1999). Impacts include direct changes, such as increased temperature and carbon dioxide concentrations and habitat loss, and increased internal nutrient loadings and decreased oxygen concentrations. These in turn affect primary production, species composition, and foodwebs and likely will increase the risk of extinctions from freshwater ecosystems.

Physical and chemical impacts lead to widespread ecological impacts in aquatic communities, ranging from complete extirpation of entire aquatic communities, to periodic mortality events in response to spills and leaks, to degraded ecosystems left more susceptible to other disturbances. In the U.S., more than 1,200 kilometers of streams have been buried by coal mine operations; the total length of streams lost worldwide due to fossil-fuel production is not known. Fisheries in another 13,000 kilometers of streams in the eastern U.S. alone have been degraded by coal mining operations, hinting at the scale of the problem globally.

Morbidity and mortality resulting from direct oil spills and leaks have attracted considerable media attention over the years, but they are not the only source of petroleum-related mortality for waterbirds and aquatic organisms. Retention ponds for produced water and other wastewater discharges, such as processing, refinery, and thermal generation plant liquid wastes, can become attractive nuisances for migratory birds and other wildlife. Ducks and other birds have landed on such retention ponds, only to die in large numbers due to oil fouling or acute toxicity. Gosselin et al. (2010) provide a historical overview of environmental incidents generated by Alberta tar sands, noting that natural bitumen discharge had been recorded along a river bank in Alberta as far back as 1719. Large-scale commercial operations began more than 40 years ago, leading to spills and releases from pipelines and tailings ponds. A 1970 pipeline spill released more than 3,000 m^3 of oil, creating an oil slick that reached more than 250 kilometers down the Athabasca River, contaminating water supplies for several communities, and likely harming aquatic organisms (though such impacts were not well monitored or reported). Subsequent sampling found that drainage from tailings ponds was acutely toxic to fish. In 2008, some 1,600 ducks died after landing in a tar sands tailings pond and becoming fouled by bitumen on the water surface (Gosselin et al. 2010).

Acid precipitation causes a host of ecological impacts, especially to aquatic resources. Acid precipitation—primarily generated by coal combustion—can increase the mobility of aluminum and other metals in aquatic systems, leading to mortality of fish and aquatic invertebrates, in turn diminishing the prey base for birds and other animals. Acid precipitation—and its degradation of water quality and dependent ecosystems—occurs downwind of coal-fired power plants; adverse impacts have been reported in China, Europe, and North America (Larssen 1999, Menz and Seip 2004).

Impacts on Human Communities

Clean water is an essential component of healthy communities. In addition to the basic human need for water for drinking and sanitation, livelihoods such as agriculture, fishing, hunting, and industrial production depend on a sufficient supply and adequate quality of water. Furthermore, water, or the ecosystems that depend on it, has cultural or spiritual importance to many communities. Therefore, water-related impacts of fossil-fuel extraction and processing not only damage the environment but also adversely affect communities and public health (Table 4.5). Because of a lack of data on community impacts of fossil fuel–related water contamination, much of the information available is anecdotal; here we use case studies to illustrate the types of potential community impacts.

Table 4.5 Examples of Water-Related Community Impacts of Fossil Fuels

Location	Process	Impacts	Source(s)
Orissa, India	Coal mining & processing	Contamination of drinking water with fluoride, manganese, nickel, and sulfate; depletion of water available for drinking and bathing.	Murthy and Patra 2006
Appalachia region, U.S.	Coal mining & processing	Contamination of drinking water causing tap water to turn black, contain orange slime, or have a foul taste or odor. Increased severity and frequency of flash flooding.	Murdoch 2009, Stout and Papillo 2004
Ecuador	Oil extraction	Approximately 17 million gallons of crude oil and over 18 billion gallons of toxic produced water spilled or dumped into rivers during oil extraction, causing contamination of domestic water sources and surface waters used for fishing.	Juhasz et al. 2009
Niger Delta	Oil extraction	Contamination of rivers and ponds from oil spills and wastes from extraction and dredging and canalization related to oil extraction, leading to loss of fish and contamination of drinking water.	Amnesty International 2010, CEHRD 2008
Alberta, Canada	Tar sands extraction	Contamination of water bodies, including the Athabasca River, with polycyclic aromatic compounds, cadmium, copper, lead, mercury, nickel, silver, zinc, and other contaminants.	Reuter et al. 2010
U.S. (multiple locations)	Hydraulic fracturing for natural gas	Contamination of drinking water wells with benzene, methane, and other contaminants—residents suspect that it is caused by hydraulic fracturing, but this link is unconfirmed. Discharge of wastewater with high concentrations of radioactivity. New research is pending.	EPA 2011, Lustgarten 2008, Urbina 2011

Drinking Water Contamination

Fossil-fuel extraction and processing can lead to contamination of sources of drinking water with a wide variety of contaminants that threaten human health. When drinking water is contaminated, communities have three basic choices: (1) find an alternative source of water, (2) treat water before drinking it, or (3) drink contaminated water and risk adverse health outcomes. Often, alternative water sources can be much more expensive; for example, in the United States bottled water can be thousands of times more expensive than tap water or may require traveling long distances at a high energy cost (Gleick and Cooley 2009). In addition to being costly, using bottled water also requires being able to lift and transport the bottles, resulting in disproportionate hardship for the elderly, disabled, and poor.

Coal mining has been linked to severe drinking water contamination in many coal mining regions. For example, in the state of Orissa, India, communities' drinking water was contaminated as a result of coal mining and processing activities. Women are particularly at risk for adverse health effects resulting from exposure to this contaminated water, as they are responsible for many household activities that involve contact with water, such as collecting the water, washing clothes and utensils, and bathing children (Murthy and Patra 2006). Some villages were even forced to relocate after groundwater was contaminated due to coal mining activities (Murthy and Patra 2006). In the U.S., coal mining in the Appalachian region has led to contamination of groundwater drinking supplies (see the case study later in this chapter).

Recent U.S. Geological Survey research has found evidence for a link between Balkan Endemic Neuropathy (BEN) and coal mining. BEN is a degenerative kidney disease that occurs in clusters in rural villages in the Balkan Peninsula and eventually leads to complete kidney failure. An estimated 25,000 people currently suffer from this disease, which was first described medically in 1956 (USGS 2001). However, the cause of the disease is still not known for certain. Patients with BEN also have a high occurrence of normally rare upper urinary tract cancers. Recently, a correlation was found between the location of the affected villages and lignite coal deposits. Additionally, well water in affected villages was found to contain organic compounds such as polycyclic aromatic hydrocarbons (PAHs), which can be toxic and could have been leached from the nearby coal deposits (USGS 2001). In the United States, states with the highest rates of upper urinary tract and other cancers also have similar types of coal deposits (USGS 2001, Orem n.d.).

A growing concern is the link between hydraulic fracturing, a process that injects water mixed with a complex and often proprietary blend of chemicals to enhance methane recovery, and contamination of drinking water supplies with benzene, methane, radiation, and other chemicals. Although practitioners claim there is no conclusive evidence to link fracking to contamination of surface-water and groundwater supplies, critics claim that more than 1,000 cases of such contamination can be traced to fracking, as well as to incidental surface spills and leaks of fracking chemicals (Lustgarten 2008, Urbina 2011). Fracking also can create links between natural gas itself and groundwater, in some instances increasing methane concentrations in drinking water to such an extent that tap water can be ignited. From the limited information on chemicals used in hydraulic fracturing that is available, either through voluntary disclosure or in states that require disclosure, we know that chemicals that can potentially cause respiratory problems or harm to the nervous and reproductive systems are used (Berkowitz 2009).

The major human community impacts associated with fossil-fuel refining, processing, and use are related to air quality. However, all of these processes can also contaminate drinking water sources with a variety of toxins. In the state of São Paulo, Brazil, for example, improper disposal of toxics at a petrochemical facility caused contamination of nearby drinking water wells (Harden et al. 2002). In the U.S., one estimate puts releases of petroleum by-products by oil refineries at 50,000 barrels per day; about a quarter of total petroleum refining toxic releases in the U.S. are to water systems (O'Rourke and Connolly 2003).

Case Study: Mountaintop Removal, Coal Mining, and Drinking Water in Appalachia

In the Appalachian Mountains, which run from the U.S. state of Georgia northeast into Canada, coal mining has been a central economic activity for generations. Increasingly, coal is extracted in this region using the mountaintop removal method, leading to large-scale environmental destruction (described earlier). Additionally, the practice has resulted in contamination of drinking water. This contamination is suspected to be primarily caused by coal slurry, which is disposed of in impoundments or by injecting it into abandoned mines, both of which can potentially leach contaminants into groundwater. Studies of well-water quality have found contaminants consistent with those found in coal slurry (Hendryx et al. 2007; McSpirit and Dieckmann 2003; Stout and Papillo 2004). Even after mine sites have been reclaimed (i.e., mining activities are completed and attempts are made to restore the site to previous conditions), groundwater has been found to contain elevated levels of mining-related contaminants (USGS 2006).

In many cases, this contamination has left families or whole communities without water that is safe to drink or even to use to bathe. Some communities with contaminated drinking water also suffer from elevated rates of health problems, including cancer, liver and kidney problems, and skin rashes—ailments they suspect are linked to their water (Stout and Papillo 2004, Murdoch 2009). But because it is difficult to determine for certain the causes of many of these diseases, the number of people whose health has been affected by drinking water that is polluted by coal mining is unknown. In one community in West Virginia, neighbors banded together to sue nearby coal companies for contaminating their drinking water. Evidence for the case was found in disclosure reports by the coal companies that showed the companies were pumping into the ground illegal concentrations of the same chemicals that were detected in drinking water (Duhigg 2009).

Loss of Subsistence Resources

Water is an important component of many livelihoods. Clean water and healthy freshwater ecosystems provide the basic goods and services upon which many livelihoods depend, from irrigation water to creating fertile floodplains for grazing. According to a UN Food and Agriculture report on water and livelihoods, "some 75% of the world's poorest people live in rural areas across the world, and for them, water access can literally mean the difference between life and death" (Sullivan et al. 2008). For many indigenous cultures, loss of subsistence resources results not only in economic or livelihood loss but also in cultural and spiritual loss. For example, the Columbia River Inter-Tribal Fish Commission states on its website that "salmon are part of our spiritual and cultural identity . . . without salmon returning to our rivers and streams, we would cease to be Indian people" (CRITFC 2010). Depletion or contamination of water resources can lead to ecosystem decline or collapse, resulting in a loss of subsistence resources. Alternatively, contamination of water resources can also lead to accumulation of contaminants in fish and wildlife, which can cause illness when people ingest them.

Case Study: Impacts of Oil Drilling on Subsistence Resources in Nigeria

Located on the coast of Western Africa, Nigeria is endowed with rich natural resources, particularly oil, but is also confronted with serious environmental and political challenges. The Nigerian economy relies heavily on oil: in 2008, crude oil accounted for 90 percent of the country's exports (UN Statistics Division 2009). Nigeria is the largest crude oil–producing country in Africa and the fourteenth largest worldwide (US EIA n.d.). Much of the oil production in Nigeria is done by large multinational companies, including Shell, ExxonMobil, and Chevron. Available information indicates that more than 6,800 spills, totaling about three million barrels of oil, have occurred in Nigeria between 1976 and 2001 (UNDP 2006). Oil spills happen both accidentally and due to vandalism of pipelines by local people in protest of oil companies and the government (UNDP 2006).

Oil spills have had severe impacts on natural resources in some parts of the country, limiting local people's ability to provide for themselves through subsistence farming or fishing, in a country where 34 percent of the population lives below the national poverty line and 64 percent of the population lives on less than $1.25 per day (UNDP 2010). Surface waters and wetlands have been have extensively damaged in the Niger Delta. For example, in 2008 there was an oil spill resulting from a break in the Trans-Niger pipeline that continued for weeks and contaminated Bodo Creek in Gokana, Nigeria. This contamination damaged many of the aquatic species that local people eat, leading a Nigerian nonprofit organization to conclude: "Given the overwhelming dependency of Gokana people's livelihood on mangrove and artisanal fisheries, it is safe to infer that the spillage will largely undermine food security in the locality" (CEHRD 2008).

Case Study: Impacts of Tar Sands on Health and Food Security of First Nations Communities

Alberta, Canada, contains approximately 175 billion barrels of proven oil reserves, largely in the form of tar sand. As discussed earlier, tar sand—a solid or semi-solid form of petroleum—requires large volumes of heated water for extraction that become contaminated with use and are often stored in toxic tailings ponds (Reuter et al. 2010). Contaminants can leak from these tailing ponds through the soil, causing contamination of nearby rivers. Recent research on the Athabasca River in Alberta, for example, has linked heavy and toxic metals—including mercury, arsenic, and lead—to nearby tar sands development (Kelly et al. 2010).

Such developments may have serious adverse effects on some First Nations (native Canadian) communities. In Fort Chipewyan, a village in Alberta, cancer rates are thought to be far higher than normal; there is disagreement regarding by how much rates are elevated (Brooymans 2010). In 2006, a local doctor pushed for an inquiry into what he believed were unusually high cancer rates among his primarily First Nations patients. He suspected that toxins dumped into the waterways by the tar sand project were to blame (Woodford 2007). This doctor was later accused by Health Canada of causing "undue alarm" when selected data from a study that it conducted indicated that cancer rates in the community were lower than overall rates in Alberta. When more complete data from the study were later released, however, they indicated that cancer rates were in fact elevated in Fort Chipewyan (Woodford 2007). While a link to tar sand developments has not been proven, many suspect that they are the cause, and improved, independent epidemiological surveys are needed.

Additionally, fish and wildlife in the area are increasingly being found to have large sores or other abnormalities, making people afraid to eat these traditional sources of food (Crazyboy 2010, Candler et al. 2010). Contaminant guidelines established to protect aquatic life were exceeded for 7 of 13 toxins examined in one study of the Athabasca River, indicating a threat to the health of fish and other organisms in the river (Kelly et al. 2010). As pollution makes traditional foods unsafe or undesirable to eat, native food security and traditions are put at risk. Speaking of the Athabasca River, one member of the Mikisew Cree First Nation stated: "We do lots of hunting in that river, not only for ducks, for moose and we do lots of fishing also. It's for our livelihood . . . you go out there to feed your kids, to feed the family. . . . And now, the moose is not fit to eat, the fish is not fit to eat, even ducks. What else are we to live on now? There's not anything fit to eat" (Candler et al. 2010).

Conclusion

The energy/water nexus has become a popular topic of inquiry, with a great deal written in the past several years about the amount of energy required to extract and move water, and about the large volumes of water required to extract fossil fuels and generate electricity. Yet very little has been written about the water-quality implications of fossil-fuel production and use, despite the fact that water quality can be degraded at every step of the fuel cycle. Extraction, refining, and combustion of fossil fuels pollute water in many ways, both through regular operations and through accidental releases or other incidents. Fossil fuels themselves are significant water contaminants; many of the chemicals used to process and refine these fuels also pose grave threats to water quality.

Unfortunately, reliable estimates of the total volumes or quality of water polluted by fossil-fuel production and use do not exist. However, some general estimates of total water required for production of various resources offer an order of magnitude–level appraisal of fossil fuel's global water-quality impacts. Not including the very large volumes of produced water that are re-injected or discharged into the oceans, on the order of 15 to 18 billion m^3 of freshwater resources are affected annually by fossil-fuel production. Much of this water is treated and subsequently discharged or held in retaining ponds, where it may evaporate or, in some cases, percolate through the soil and degrade groundwater. The severity of fossil fuel–generated water pollution varies tremendously. Some acid mine drainage is so toxic that it has effectively sterilized receiving waters; other impacts may be relatively minor and short-term.

Coal, natural gas, and petroleum are produced in every major region of the world. Similarly, the contamination of water due to fossil-fuel extraction and processing occurs around the globe. This contamination of water has significant implications for ecosystems and for communities that depend on the water for drinking or to support their livelihood. In some cases, accidents or other incidents can temporarily degrade water quality, with limited impacts to ecosystems or human communities. In other cases, such as unmitigated mine drainage or mountaintop removal, fossil-fuel production can generate chronic impacts that render a water source unusable. At the global level, the single greatest water-quality impact generated by fossil fuels comes from fossil-fuel combustion and subsequent climate changes, which will have major, long-term water-quality impacts across the planet.

Despite these impacts, information on global water-quality impacts of fossil-fuel production is scarce, old, incomplete, or nonexistent. As the world moves toward increased production of unconventional oil and gas, which typically require vast quantities of water and have a large potential for contaminating nearby freshwater systems and groundwater, these impacts are likely also to increase. Several relatively new methods of fossil-fuel extraction, such as fracking, can cause widespread contamination of groundwater resources, affecting drinking water systems and both surface water and groundwater. This chapter offers an initial assessment of the water-quality impacts of fossil-fuel production and use, but much more work needs to be done to better understand the scope and intensity of such impacts.

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