Chapter 2
The planet and its natural resources

2.1 Earth

We live on a planet uniquely endowed with a rich and beautiful mosaic of life forms, and we also have the unique responsibility of protecting and taking care of this mosaic. We are not separate from the environment, but part of it. This chapter describes the Earth from the perspective of its physical systems, material flows and natural resources. These systems and flows form the basis of the life support systems that made, and continue to make, life possible on the planet.

The planet itself has a sophisticated structure from which we have direct experience of only a minor part. The inner part is molten while the outer core is semisolid. The core is identifiable since it generates the Earth's magnetic field. The heat in the inner part of the planet comes mostly from radioactive decay. The heat from the Earth is used in many forms of technical heating systems, and provides a sustainable source of energy.

Around the inner core is the *mantle*. It floats on top of, or outside, the core since it consists of light elements such as silica, oxygen, magnesium, aluminium, sodium and potassium, forming a more or less molten, pliable rock. The mantle reaches down to a depth of about 2,900 km. During eruptions of volcanoes it appears on the surface as a floating molten rock material, called magma. Outermost, on top of the magma, is the *crust* of the planet. This is the solid rock with which we are familiar. It is in this perspective quite thin. Under the oceans it reaches about 10 km in depth and on the continents up to 40 km in depth, which is from 0.2 to 0.7% of the distance to the centre.

The most common type of rock on Earth formed from solidified magma and is called *igneous rock*. Included in this category are the fine-grained rocks from magma that cooled quickly after a volcanic eruption, such as basalt; and coarse-grained rock from slowly cooling magma, such as granite and gabbro.

Rock that has been modified by heat, pressure and chemical reactions, as exerted, for example, by tectonic movements or the weight of sediments, is called *metamorphic rock*. Common metamorphic rocks include marble, formed from limestone; and quartzite, formed from sandstone.

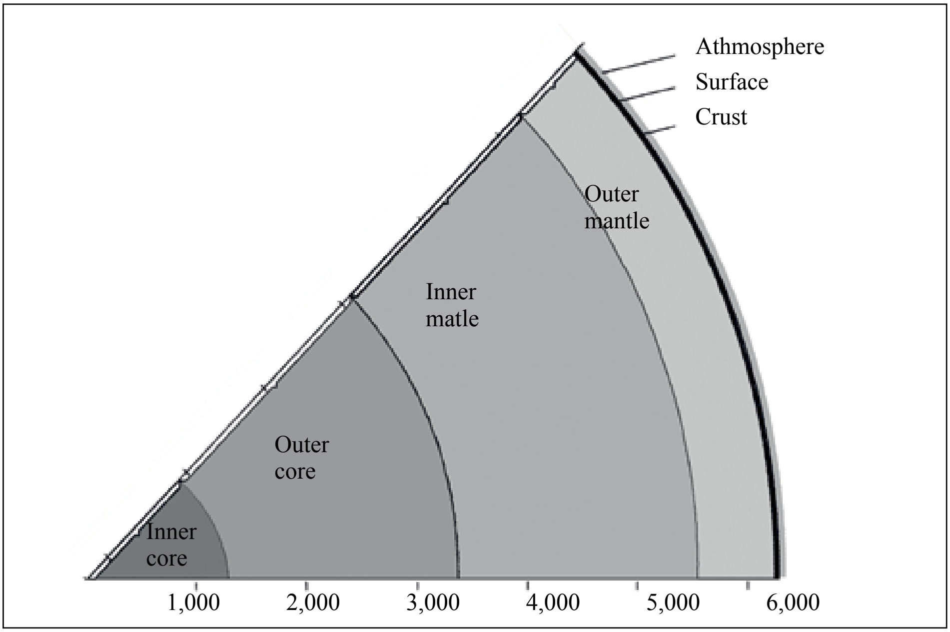

Figure 2.1. Structure of the Earth. The four major components of the planet are the inner and outer core and the inner and outer mantle, together constituting some 99.5% of the radius. On top of these is the outermost layer, the crust. It spans from 10 km in depth (under the oceans) to 40 km in depth (under the continents). The layer of soil on the surface of the crust on which life depends is, in this perspective, a minute and vulnerable outer skin. (Source: Environmental Science, Baltic University press, 2003).

Most rocks are very durable but exposure to air, water, and temperature variations eventually cause them to finally break up in the process of *weathering*. Examples of mechanical weathering are when water between fragments freezes, expands and causes a physical break; or simply when pieces are rubbed against each other during movements, e.g. by inland ice during glaciation. Chemical weathering occurs when a chemical reaction such as oxidation, or acidification caused by carbon dioxide, dissolves a component of the rock.

The particles created by weathering constitute *the soil*, and are transported by wind and water in the process of *erosion*. Finally, the particles are deposited in low parts of the landscape in the process of sedimentation, which creates valley bottoms and plains. Common soil types include till (rock-debris deposited by retreating continental ice), loess (very fine particles transported by wind), the coarse sand and gravel transported by water in rivers and brooks, and finally the sand, silt and very fine particles of clay that are deposited as sediment from the water column in lakes and oceans and thus make up ocean and lake bottoms.

Soil is found in valleys and plains, but also in other places where particles are kept from being carried away in the process of erosion. The sediments, e.g. in ocean bottoms, solidify due to the high pressure created by the continuous addition of new sediments. This rock forming process forms *sedimentary rock*. Examples of sedimentary rock are shale, sandstone, and conglomerates (aggregates of sand and gravel).

The creation of soil suitable for plants to grow in is thus based on very slow geological processes. Compared to the size of the planet, the layer of arable soil is small and sensitive. It is often not more than a few metres deep, and sometimes only a few centimetres deep, but it plays an important role in the geological formation of the surface of the Earth. Humankind needs to consider how to keep the soil layer in a state where it can continue to support life processes.

2.2 Rock and soil as resources

The Earth's crust, *also called the lithosphere*, contains minerals, metals, and other materials that are essential to human society. In fact, civilisations have been named after metals extracted from it. Stone, bronze (made up from copper and tin), and iron have been used to name periods of human history.

In modern times (after 2000), hundreds of different materials are extracted from the Earth's crust. The amounts of *metals* most extracted are 2800 mega tonnes iron, 47 mega tonnes aluminium, 22 mega tonnes manganese, 18 mega tonnes copper, and 14 mega tonnes chromium yearly.

However, the largest amounts are extracted of *sand and gravel*, used for example in brick, concrete and other forms of building material. As well, large amounts of limestone are used to produce concrete. In addition, considerable amounts of other materials are moved in connection with mining.

The landscape on the planet – the valleys and mountains, water and land, and rock outcrops and soil – is the result of recent processes in terms of geological time, and occurred in the Quaternary period (the last 1.6 million years). Man has made major changes to the landscape, especially during the last few generations. Examples are deforestation, drainage operations, and construction of infrastructure such as large dams for hydropower. The amount of material involved is large. It has been estimated that by building excavations, road building, and mining operations man moves about 35 giga tonnes of material per year world-wide. Sediments in rivers hold another 10 giga tonnes of material added by man per year. Other than plate tectonics, these man-made operations are the largest geological processes on Earth.

Figure 2.2 Blue Marble Earth. The Blue marble images are the most detailed true-colour images of the entire Earth to date. Using a collection of satellite-based MODIS observations, scientists and visualizers stitched together months of observations of the land surface, oceans, sea ice, and clouds into a seamless, true-colour mosaic of every square kilometre of our planet. Source: NASA Goddard Space Flight Centre. Credit: Reto Stöckli, NASA Earth Observatory. (http://visibleearth.nasa.gov/view.php?id=73580)

Soil is a key resource as it supports all organic life. In a typical soil profile, organic carbon concentrations are decreasing exponentially with depth. About the same amount of carbon is usually found in the upper 25 cm as in the subsoil between 25 and 100 cm depth. This can be visually observed when digging a soil pit where the darker upper horizon indicate a high carbon content compared to deeper horizons which are more greyish or reddish due to less amounts of minerals and oxides with organic material. Soil organic carbon content is a key-indicator for soil fertility since it affects soil structure and is positively correlated with aggregate stability, water infiltration, water holding capacity, nutrient delivery, nutrient use efficiency and soil erosion control. Therefore, keeping reasonable high levels of soil organic carbon is essential to sustainability.

But in contrast soil is lost at an accelerated rate. Society induced tremendous changes in the land surface area of the planet has deceased soil. Especially society has increased the speed of *erosion*. Biological processes slow down erosion, especially since plants bind soil in areas where it would otherwise be lost. However, if plants are removed by human intervention, erosion is speeded up. Erosion occurs whenever land is made barren of plants. The amount of soil moved by erosion from agricultural land is massive. Farmland is extremely sensitive to erosion by rain and wind when left in fallow for long periods. This is a major threat towards the productivity of large areas. The soil ends up in rivers where it is transported to lakes and oceans, adding to sediments and magnifying natural processes.

In addition modern agricultural methods, especially ploughing, have dramatically increased the loss of soil. A main reason is that as organic material is exposed to air, it is oxidised by soil microorganisms. It results in the emissions of carbon dioxide from land and contribute to climate change and loss of valuable soil. The large plains in Europe and North America have in this way lost meters of soil since they were colonized, while fertile areas in Africa, as well as the Amazonas, have undergone the same process because of overgrazing and deforestation. The world's population increases while the amount of productive farmland began declining in the 1970s. The United Nations Framework Convention to combat desertification was set up exactly to find ways to slow and reverse these processes.

2.3 The atmosphere and the sun

As described above we live on top of an immense layer of solid material, measured from the centre of the Earth. But we also live at the bottom of an immense "ocean" of air, the *atmosphere that* reaches up about 1,600 km. It is composed of gaseous elements, many of which are essential to life on Earth. The present oxygen content of 20% was probably reached about 300 million years ago. Simple oxygen breathing, mono-cellular organisms have been present for more than a billion years. Large animals, which require a higher oxygen concentration, appeared on a geological scale rather abruptly some 670 million years ago. Human beings cannot function well with a much lower oxygen concentration than is currently present. This can easily be experienced during high altitude mountain climbing.

The atmosphere is structured in four rather distinct layers. Closest to the surface of the Earth is the *troposphere*. It reaches up at the most 18 km at the equator and 8 km at the poles. The troposphere contains most, about 75%, of the mass of the atmosphere, simply caused by gravitation. The troposphere is where the weather phenomena occur. It is therefore very thoroughly stirred and, thus, has a quite uniform composition of gases. The temperature decreases throughout the entire troposphere by about 1°C per 100 metres, and is about -60 °C at the top.

The sun shines on the planet with an intensity of about 1,330 Watts per square metre at the outer reaches of the atmosphere, and varies according to location and time of year. About 25% of incoming solar radiation is reflected by the clouds and the atmosphere and does not contribute to the heat balance of the planet. The atmosphere and clouds absorb another 25%. Only half of the solar radiation thus reaches the surface of the Earth, some being again reflected, or backscattered.

About 45% of incoming radiation is finally absorbed by the surface of the planet. This energy is used for e.g. evaporation of water. All of it is, however, in the end radiated back to maintain heat balance. However, since the outgoing radiation comes from the colder Earth it is very different from the incoming radiation. It is mostly low energy, longer infrared wavelength radiation (heat radiation). The atmosphere is much less transparent to outgoing heat radiation than it is to the incoming solar light. Thus, much of the energy is used to heat up the lower atmosphere and indirectly the surface of the Earth. This effect contributes to the heat balance of the planet with about 35 ^{o}C. Without this effect, the Earth would not harbour life as we know it. The heating through absorption of infrared back radiation is called the "greenhouse effect," comparing the atmosphere to the glass in a greenhouse that makes the inside warmer by absorbing outgoing radiation. The most important component in the Earth's atmosphere that absorbs the infrared light from the Earth is water vapour. However, any gas that absorbs infrared light contributes. Most important are carbon dioxide and methane. The concentrations of each of these gases are decisive for the heat balance of the planet. The present dramatic increase of carbon dioxide and other greenhouse gases is obviously influencing this balance and causes a shift towards a warmer climate, called the *enhanced greenhouse effect.*

The gases of the atmosphere are important resources for mankind and all life. Carbon dioxide is incorporated (assimilated) when by photosynthesis organic material is built up. In this way huge amounts of carbon are sequestered from the atmosphere. Oxygen are used in all kinds of combustion processes. In calculations of material turnover oxygen is included, either as air or as oxygen gas itself. It is, however, never limiting. Nitrogen gas is used to produce ammonia for all kind of chemical needs, in particular as fertiliser. As gaseous nitrogen is a very stable diatomic molecule large amounts of energy is required to reduce it to ammonia in the Haber Bosch process. It is a main use of fossil fuels and thus contribute to climate change.

The solar input is the base for all life and energy on our planet. The energy available for processes on the surface of the Earth, such as the hydrologic cycle, photosynthesis and heating of soil layers and vegetation, is called the net radiation. This is the net income of energy to the Earth's systems. Net radiation consists of the nets of long-wave and short-wave radiation. In the energy balance of the Earth's surface the net radiation is distributed between sensible heat flux (heating air and vegetation), latent heat (evapotranspiration) and ground heat flux (heating the ground).

Fossil fuels are stored “solar energy” as it consists of organic material formed millions of years ago. To use this is not sustainable but the direct use of solar energy in one or several of it forms is sustainable. It is the most essential of natural resources and is not limiting. Presently society uses only less than 0.1 per mille of the incoming solar radiation.

2.4 The water planet

The third crucial component of the planet is water, or the *hydrosphere*. Water is a very special substance. It is part of all living cells. On average, about 70% of a living organism is water. It is a perfect solvent for all kinds of ions, charged molecules and many of the chemicals that make up the fundament of living cells. Water constitutes a liquid in a temperature range that is perfect for life, and in fact is the only substance with such properties. When it solidifies to ice it becomes slightly lighter and thus floats on liquid water, a behaviour which is also quite

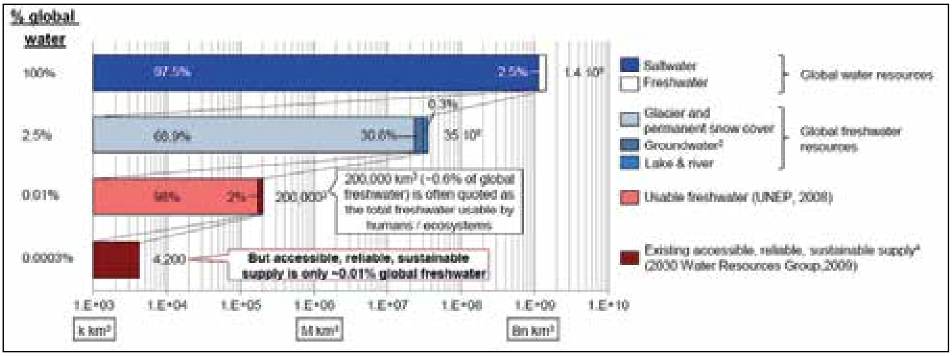

Figure 2.3 An Overview of the State of the World’s Fresh and Marine Waters. (Source: UNEP (2008); 2030 Water Resources Group (2009); “Charting our water future”; SBC Energy Institute analysis).
Notes:
1 The segments representing small percentages at the right – hand end of the first three bars have been enlarged for readability purposes;
2 Ground water includes shallow and deep ground water basins up to 2,000 meters, soil moisture, swamp water and permafrost;
3 Renewable internal fresh water resources (internal river flows and ground water from rainfall in a country), which amounted to 42,369 km^3 worldwide in 2011 (World Bank database), represent another theoretical upper limit for the water that can be withdrawn from natural systems but in practice accessible, reliable, sustainable supply is far lower (~4,200 km^3);
4 Existing supply that can be provided at 90% reliability, based on historical hydrology and infrastructure investments scheduled through 2010; Net of environmental requirements, and excluding use of fossil (non-renewable) ground water reserves not sustainable in the long term.

unique. It takes a considerable amount of energy to vaporise water, and thus it stays liquid over an unusually wide temperature range.

There is about 1,403 million km^3 of water on the Earth. If this was evenly spread out over the planet, and if the surface was smooth, it would cover the whole Earth in a layer about 3 km deep. The surface is of course not smooth and about 70% of the surface of the planet is covered by water. Most water on Earth is not immediately useful to us. Ocean and saline water accounts for about 97.6% of all water on Earth. The rest, 33,400 km^3, is fresh water. Most of this is bound in ice and glaciers. Liquid fresh water makes up 4,400 km^3. It is distributed between about 4,000 km^3 of ground water and smaller amounts of surface water. Lakes, rivers and brooks, wetlands, etc., contain about 130 km^3 on the Earth as a whole, and the atmosphere holds about 13 km^3. Considerable amounts are contained in biota (65 km^3) and soil moisture (65 km^3).

Surface water is constantly re-circulated in what is called a natural *hydrological cycle*. Water evaporates from land, surface water and organisms. It enters the atmosphere and forms clouds as it condenses. It is transported by the winds and as it cools, especially at higher altitudes over mountains, it precipitates as rain and snow. Back on the ground it flows by gravity, coming back to the sea. The water flow described involves a considerable amount of energy. Mass (here water) present at higher altitudes contains *potential energy*, i.e., the flow down to lower levels represents an enormous amount of energy, which is used in e.g. hydropower plants.

Evaporation of water from land surfaces and transpiration from plants, called evapotranspiration, constitutes a considerable flow of water. In the reverse process, *condensation*, water vapour forms droplets of liquid water. Most often, condensation leads to cloud formation. When it occurs on ground or plant surfaces the water that appears is called dew. Some plants get all their water from dew. Precipitation occurs when water condensed in clouds forms large enough water droplets. Precipitation varies over the globe from several thousand millimetres per year down to almost zero. As a whole, the Aral Sea basin (1,76 M km^2) receives 65 km^3 of water per year. This corresponds to about 4 cm of water if spread out evenly over the entire region. This is the potential annual runoff from the region. Subtracting the annual evapotranspiration gives the actual yearly runoff. The *water balance* can thus be formulated as: runoff is equal to precipitation minus evapotranspiration. It is very low for the Aral Sea basin.

The hydrologic cycle includes the slow movement of ground and soil water. Here, movement is typically in the order of metres per year, as compared to metres per second for streams and metres per days for lakes. The storage of water

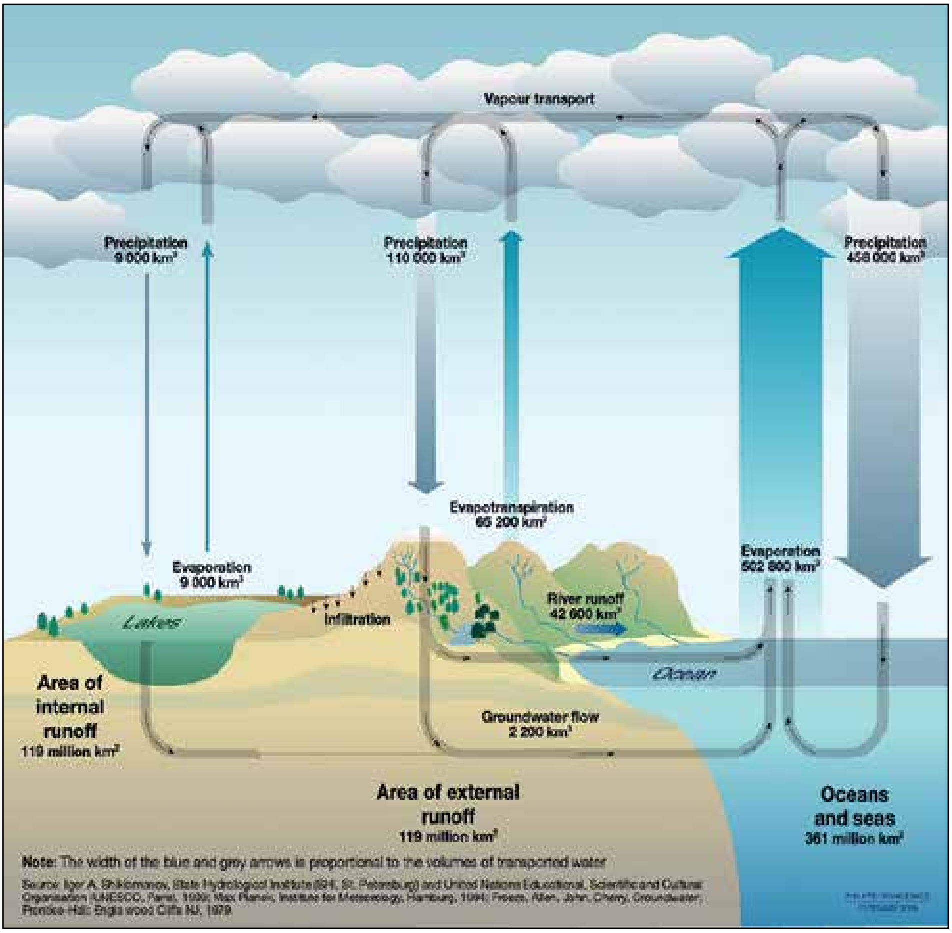

Figure 2.4. The water cycle consists of precipitation, vapour transport, evaporation, evapo-transpiration, infiltration, groundwater flow and runoff. Figure 1 explains the global water cycle, illustrating how nearly 577,000 km^3 of water circulates through the cycle each year. A table of estimated residence times shows the approximate times that water resources exist as biospheric water, atmospheric water and so on.
The world's surface water is affected by varying levels of precipitation, evaporation and runoff, in different regions. Figure 2 illustrates the different rates at which these processes affect the major regions of the world, and the resulting uneven distribution of freshwater. Water is transported in various forms within the hydrologic cycle. Shiklomanov in Gleick (1993) estimates that each year about 502,800 km^3 of water evaporates over the oceans and seas, 90% of which (458,000 km^3) returns directly to the oceans through precipitation, while the remainder (44,800 km^3) falls over land. With evapo-transpiration and evaporation totalling about 74,200 km^3, the total volume in the terrestrial hydrologic cycle is about 119,000 km^3. Around 35% of this, or 44,800 km^3, is returned to the oceans as run-off from rivers, groundwater and glaciers. A considerable portion of river flow and groundwater percolation never reaches the ocean, having evaporated in internal runoff areas or inland basins which lack outlets to the ocean. However, some groundwater that bypasses the river systems reaches the oceans. Annually the hydrologic cycle circulates nearly 577,000 km^3 of water (Gleick, 1993). http://www.unep.org/dewa/vitalwater/jpg/0102-water-cycle-EN.jpg

in the ground and soil functions to even out water supply in nature. Even after prolonged draughts, some water is left in the soil and as ground water.

There are two implications of these aspects of water storage. First, seasonal water balances must include changes in the amount of water stored in the ground and soil. Second, polluted ground water moves slowly and may remain a problem even for future generations.

The water balance is connected to the heat balance by evapotranspiration. Net radiation is the driving force and sets the limit for evapotranspiration. In this way, the hydrological cycle is powered by precipitation which is the mass income, and net radiation is the power source.

The hydrological cycle thus constitutes a large solar powered pump that moves water and substances carried by water. Water evaporates in warmer areas, is transported by weather systems and precipitates in other colder areas. Many organic pollutants are in this way transported from southern areas to the north and even further north, to e.g. Greenland, which thus receives pollutants that did not originate locally.

2.5 Water as a resource

Water resources have probably influenced humans more than any other natural resource and are still one of the most important prerequisites for civilisation. Since human beings first settled, easy access to drinking water and water as a transport medium has been necessary to stable and lasting settlements. A quick glance at a map still shows a concentration of villages and cities to coastlines and rivers. In areas where freshwater is scarce the inhabitants spend a considerable amount of time every day collecting water, and development of such societies has been slow. In the developing countries, at least one fifth of the people living in cities and three quarters of the rural population lack access to reasonably safe supplies of water, while many of the industrialised countries are experiencing serious problems regarding water pollution, scarcity and wasteful use.

The availability of freshwater in terms of location and quantity is essential to all societies and consequently there are few natural resources of which our knowledge is more advanced. Despite this extensive knowledge, the exploitation of water resources is done on such scales, ranging from individual households to cities of several million inhabitants, that even more detailed knowledge, especially concerning interaction between the different users, is called for.

A further complication is the variability of water availability, not only spatially but also temporally. In many areas of the world freshwater is scarce, which creates a problem if the population demand is not in harmony with the available resources, even if these areas normally have spots of high water availability, e.g. oases. Availability is also an issue in areas where water is plentiful, but where the quality is low because of pollution, or where the demand is extremely high.

Around the world we see today surface water, water in rivers and lakes, to be overused. A most blatant case is the Amu Darya and Syr Darya drainage basin, where water has been extracted for irrigation to the extent that the Aral Sea is almost disappearing. Another case is the Colorado River, one of the largest river in North America, which for millions of years have been flowing from its sources high in the Rocky Mountains to channel water south nearly 2 500 km, over falls, through deserts and canyons, to the lush wetlands of a vast delta in Mexico and into the Gulf of California. Since the 1920s, Western states began dividing up the Colorado's water, building dams and diverting the flow hundreds of miles, to Los Angeles, San Diego, Phoenix and other fast-growing cities. The river now serves 30 million people in seven U.S. states and Mexico, with 70 percent or more of its water siphoned off to irrigate 3.5 million acres of cropland. Today we can see lines in the rock walls, distinct as bathtub rings, showing the water level some 4 meter lower, as it happens, since 2000.

Just as river waters have been over-used and polluted in many parts of the world, so too have groundwater aquifers. Groundwater tables are thus sinking all over the world, to the extent that many areas are already experience severe water

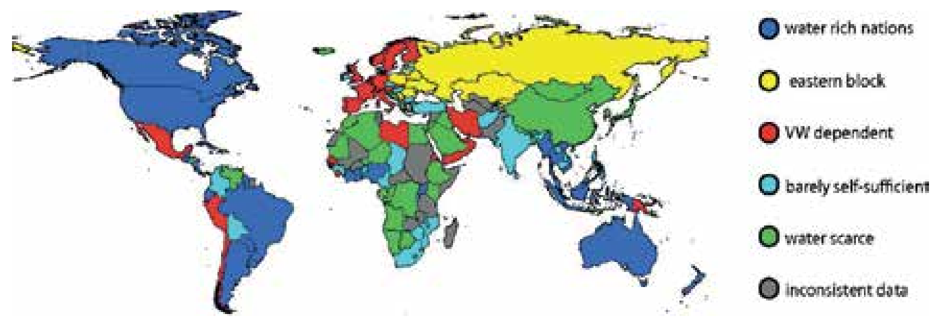

Figure 2.5. Worlds water resources. Map of the world's countries classified on the basis of their dependency on local (loc) and virtual (V) water resources, based on data for the 1996–2005 period. Countries are water rich when their mean population, X, is less than 0:8 Kloc (K_{loc} =average local carrying capacity); virtual water dependent if $K_V > X > 1{:}20\ K_{loc}$; barely selfsufficient if $K_{loc} \approx X$ (i.e., 0:80 $K_{loc} < X < 1{:}20\ K_{loc}$); and water scarce if $X > K_V > K_{loc}$ (V= virtual water). Countries for which the data exhibit inconsistencies (i.e., $X > K_{loc} > K_V$) are shown in gray. A separate analysis has been carried out for the countries from the influence zone of the former Soviet Union (or the "Eastern Bloc") because in the past two decades their demographic dynamics have been affected by major political changes not related to freshwater resources. (Source: Samir Suweisa, Andrea Rinaldob, Amos Maritana, and Paolo D'Odoricod www.pnas.org/cgi/doi/10.1073/pnas.1222452110.)

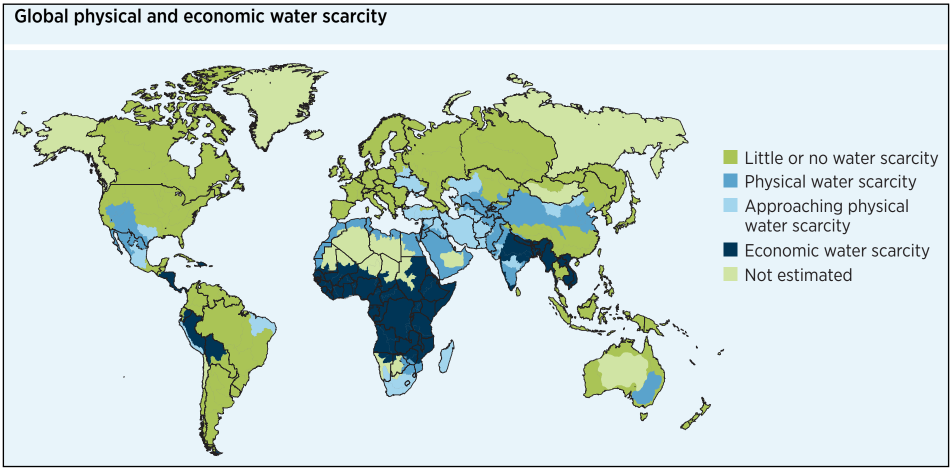

Figure 2.6 Water scarcity. (Source: Comprehensive Assessment of Water Management in Agriculture (2007, map 2, p. 11). © IWMI, used under licence.)

scarcity or are in risk of doing so. Climate change will likely increase the problems. Droughts will last longer. Higher overall air temperatures will mean more water lost to evaporation, and that water will be scarcer during the growing season,

Other regions - the Mediterranean, southern Africa, parts of South America and Asia - also face fresh-water shortages, even outright crises. In the Andes Mountains of South America, glaciers are melting so quickly that millions of people in Peru, Bolivia and Ecuador are expected to lose a major source of fresh water by 2020. In south-western Australia, which is in the midst of its worst drought in 750 years, fresh water is so scarce the city of Perth is building plants to remove the salt from seawater. More than one billion people around the world now live in water-stressed regions, according to the World Health Organization.

2.6 Use of carbon

Human activities have substantially altered both pools and flows in the natural carbon cycle. Combustion of fossil carbon and deforestation are the main causes for the 30 per cent increase in atmospheric CO_2 concentrations. A continued increase is expected to cause significant climatic changes. This will be further analysed in the following chapters. Here we will briefly highlight various features that need consideration when discussing the societal metabolism of a future sustainable society, in terms of utilisation of fossil carbon and biospheric carbon. For food and many materials, human society still completely depends on products of photo-synthesis and, until the middle of the 19th century, biomass also dominated global energy supply. Although fossil fuels have taken over as the dominant source of energy, biomass still accounts for more than 10 per cent of global primary energy supply and is widely used in developing countries.

Approximately 75 per cent of the global energy supply is based on fossil fuels, namely, coal, oil and natural gas. Combustion of both fossil and biomass carbon gives rise to CO_2 emissions but emissions from biomass burning are recaptured by plants if they are regrown. Thus, biomass has the potential to be a CO_2-neutral energy technology. At present, combustion of fossil fuels give rise to emissions of 6.0 Gton C/year and land-use changes, mainly deforestation of tropical rain forests, give rise to an additional 1-2 Gton C/year.

The use of fossil carbon is around ten times larger than the total use of all metals in society. It is also worth noting that fossil fuels contain vast quantities of heavy metals and other elements. Flows of elements associated with the extraction of fossil fuels are actually greater than the amounts that are mined for several elements, for example, aluminum (Al), vanadium (V), lithium (Li), gallium (Ga), beryllium (Be), mercury (Hg), silicon (Si), germanium (Ge), sulphur (S) and selenium (Se).

Fossil carbon is also used to produce plastics and other organic chemicals, for example, lubrication oils, solvents and printing inks. When eventually broken down these will also give rise to emissions of CO_2. In addition, some specific industrial processes give rise to net emissions of CO_2. Changing the production process may eliminate all greenhouse gases associated with a certain industrial operation. Although, there are some cases where the release of greenhouse gases is intrinsic to the product, making materials substitution is the only option for reduction of greenhouse gases. Cement production is one such example, where process-related emissions contribute 40 per cent of total emissions of lithospheric CO_2 to the atmosphere (in calcination CO_2 is driven off from the carbonates). This means that they are much lower than energy-related emissions but, in a future global industrialized society, these emissions alone may reach a rate which is high enough to cause atmospheric concentrations to continue to increase even if emissions from the energy sector are phased out.

Societal use of biomass and fossil fuels also leads to unintentional emissions of carbon in the form of methane. Emissions originate from leakage of natural gas, coal mining, biological processes in oxygen-poor environments such as rice paddies and digestion by ruminants. Global anthropogenic emissions are around 0.4 Gton/year, which is more than twice the natural rate of methane emissions.

2.7 The macronutrients and the environment

The macronutrients – nitrogen (N), sulphur (S), phosphorus (P), calcium (Ca), potassium (K), sodium (Na), magnesium (Mg)) – are elements needed in relatively large amounts in living organisms. The environmental status and availability of the macro-nutrients are very important for the composition, growth and vitality of ecosystems.

The conversion of macro-nutrients in nature is to a large extent connected with biological processes. These extensive processes heavily influence the state of the environment, for example, the acidity in soil, the chemical composition of surface waters and the radiative balance and chemistry of the atmosphere. In the evolution of the Earth, biological processes have been a major factor in the shaping of the cycles of the macronutrients, now determining the conditions for the biota in various ecosystems.

A major disturbance of the natural nitrogen flows comes from an intensification of the nitrogen cycle by increased fixation. Global fixation has increased by a factor of two or three. With the present excess fixation rate, the accumulated fixation over 50 to 100 years would correspond to the total amount of nitrogen stored in the living biomass. Nitrogen is fixed industrially in ammonia synthesis. Ammonia is a basic chemical in industry and nitrogen is contained in products such as nylon. However, the production of fertilizers for the agricultural sector produces the main demand for ammonia and is the major contributor to anthropogenic nitrogen fixation. To increase crop yields, biological nitrogen fixation is also enhanced by the choice of nitrogen-fixing plants (through symbiosis). Large amounts of nitrogen are stored in organogenic soils. Agricultural uses of these soils often rapidly activate and deplete this storage together with the organic material.

Fixed nitrogen is also emitted in combustion processes. This nitrogen has two sources. Some of it originates from the combustion air (thermal nitrogen and prompt nitrogen). Nitrogen is also present in the fuel (fuel nitrogen). The extraction of fixed nitrogen with fossil fuels amounts globally to approximately 60 Mtonnes per year, which is the same order of magnitude as from chemical fertilizers. However, only a fraction of the fuel nitrogen reaches outside the combustion process because of pyro-denitrification of the fuel nitrogen in the combustion process (or because of any added nitrogen emission counter–measures.) The net effect on the balance of fixed nitrogen in the ecosphere depends on the fuel source. For fossil fuels there is a net contribution, while burning of biomass normally gives a net loss. Most of the fixed nitrogen is emitted as various nitrogen oxides, in summary written as NO_x.

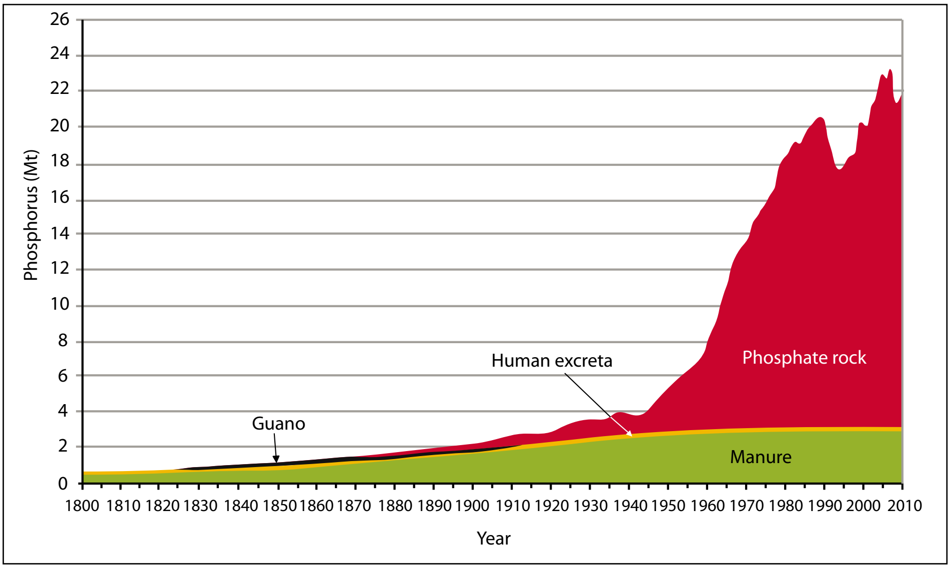

Figure 2.7 Global sources of phosphorus fertilizer. Since the mid-1940s, population growth accompanied by greater food demand and urbanization have led to a dramatic increase in the use of mined phosphate rock compared with other sources of phosphorus. (Source: Cordell et al. (2009) and Source: UNEP Year book 2011)

Fixed nitrogen leaves the ecosphere through decomposition of nitrogen compounds to N_2, mainly through biological denitrification of nitrate into N_2. By sedimentation, part of the nitrogen is also withdrawn from chemical activity in the biosphere.

Combustion of nitrogen-containing biological materials may also contribute to losses of fixed nitrogen from the ecosphere. The burning of biomass in the tropics has been estimated to yield a loss of 5-52 Mtonnes organic N, which can correspond to a substantial fraction of the total biological nitrogen fixation in the area and may lead to a deficiency situation. Combustion of nitrogen-rich biomass, such as forestry residues, in boilers with low emissions of fixed nitrogen (partly or wholly due to regulations) resulting in a net pyrodenitrification has been suggested as a way of compensating for the nitrogen excess due to air deposition in industrialized countries.

Sulphur in a reduced form can easily be oxidized and give rise to acidification. The main human-induced problems associated with the sulphur cycle are thus connected to emission to the atmosphere or exposition at the Earth's surface of not fully oxidized sulphur. Sulphur is extracted from the lithosphere in different ways:

- with minerals rich in sulphur, such as native sulphur or pyrite, that are extracted for their sulphur content;
- as sulphur impurities in fossil fuels;
- in metal-bearing sulphide minerals;
- as sulphates, mainly gypsum.

The first three forms contain sulphur in a reduced form, while in gypsum, a hydrated sulphate salt, the sulphur is already oxidized and neutralized. Most sulphur extraction takes place with the extraction of fossil fuels, especially coal. Half of the sulphur in fossil fuels is emitted to the atmosphere. Less than half is caught in ashes or in desulphurization plants or is recovered for industrial use.

The mining of sulphidic metal ores gives rise to sulphur in mine tailings and dumps and brings sulphur into metallurgical processes. On a world-wide scale the mean recovery factor of sulphur in global copper production is around 70 per cent.

The world-wide industrial use of sulphur is around 60 Mtonnes/year, that is, less than one-third of what is extracted from the lithosphere; see Figure 6.2. More than half of the sulphur is extracted from the by-flows associated with fossil fuels use and metals production. The major proportion is used for production of sulphuric acid which has a very diverse use in industry, although around 58 per cent goes into the extraction of phosphorus, another macronutrient used mainly in the production of fertilizers. For each kilogram of phosphorus, about two kilograms of sulphur are needed.

Anthropogenic emissions, mainly from the industrialized countries, make up three-quarters of total emissions. The transfer from the lithosphere is largely caused by the anthropogenic contribution, which is concentrated in the mid-latitude northern hemisphere. Society has increased the transfer from the lithosphere to the atmosphere by about a factor of 10.

Phosphorus is extracted from the lithosphere, mainly in the form of various apatites (principally calcium phosphates). The main societal use of phosphorus, about 90 per cent, is as fertilizer in agriculture. Approximately 22 Mt (megatons = millions of tons) of phosphate rock were used in agriculture in 2011. Extraction has increased dramatically with the enhanced use of fertilizers (4.8 per cent/year since 1900). Phosphorus is also used as an additive in food and fodder. The second largest use is as a component in washing detergents. The use of phosphorus thus occurs to a very large extent within the food sector. In its other uses, most of the phosphorus is discharged in waste water. It is a main cause of large scale eutrophication of coastal waters.

Base cations are extracted from deposits of sediment and evaporites in the lithosphere. They are used as fertilizers and pH-regulators in agriculture, as base chemicals in industry and in the manufacture of cement, which has led to their accumulation within infrastructure and buildings.

Base cations are brought with the extracted fossil fuels. Burning fossil fuels gives alkaline bottom and fly ashes. Earlier the fly ash partly compensated for the acidic components in the exhaust gases. But the fly ash is easily caught in filters and was one of the first emissions to be decreased, thus increasing the acidification potential of the untreated parts of the emissions.

Besides the increased input in the macronutrient cycles, *there is an increased leakage and redistribution of the nutrients available in the ecosphere*. The substitution of highly manipulated cultural ecosystems for natural ecosystems in agriculture, and also to some extent in forestry, and intensive animal husbandry have led to large increases in the leakage of nutrients, especially nitrogen, to air and water and further to various ecosystems. Their leakage varies with the specific system and the applied practice, but is larger than in the natural system they have replaced. While natural systems have been forced during evolution to develop and rely on fairly closed nutrients cycles, agricultural ecosystems are driven towards other goals and also have the possibility of being compensated for their losses of nutrients. For nitrogen, the major leakages are ammonia to air from stables and manure and nitrate to water from agricultural soils. Ammonia (NH_3) emitted to air is the source of approximately half of the atmospheric deposition of nitrogen compounds in Europe.

Within societal systems for growing, handling and using organic materials, there are large redistributions of nutrients bound to organic materials taking place at various levels and scales. In agriculture, specialization leads to fodder redistribution and concentration of nutrients in animalrich farms and regions. In soils with no recycling of harvested products, nutrient deficiency will quickly develop if there is no external supply. Trade in food and fodder takes place on a global scale, depending on, for example, soil abundance and conditions for growing different crops and economic circumstances.

2.8 Metals in nature and society

Today, approximately 30 metallic elements are made commonly available in society through mining and processing of their ores. Many metallic elements are used in their pure forms, however, because of their unique properties. Chemical mixtures (alloys) of two or more metals, or metals and non-metals, often have superior properties of corrosion resistance, durability or strength.

Iron totally dominates societal use of metals; compared to other materials flows in society, the flows of metals, except for iron, are relatively small. But metals are technically and economically very important to industrialized society and this is reflected in their relatively high prices. Many other metals are closely linked to the use of iron as *ferro-alloy metals*. Partly because of their relatively low weight, society uses an increasing amount of the abundant light metals, especially aluminium, but also titanium and magnesium. Society still also uses a lot of the traditional *non-ferrous metals* or *base metals*, for example, copper, lead, zinc, tin and mercury.

The *precious metals* of antiquity, gold and silver, were called noble metals. Today the so-called platinum group elements are also called precious or noble metals because they too exhibit non-reactive properties.

Finally, there is a group of metals, the *special metals* that do not fit into the categories mentioned above. These metals have unusual properties that make them important in industry. Tantalum, for example, is widely used in electronics because of its special properties.

Many metals are scarce but valuable and are therefore extracted from ore of a low grade. Despite the relatively low volume of extracted useful metals, *some metals contribute extensively to the ecological rucksack, that is, mining waste.* Iron, because of the large volume used in society, and copper, because of its low-grade ores, give rise to huge amounts of discarded useless materials in mining and concentrating operations and also in subsequent metallurgical processes.

The extraction of five grams of gold (about the amount in a wedding ring) needs the excavation of around one cubic meter of lithospheric materials. The rucksacks consist mainly of large dumps and translocations of materials at the mine and may give rise to mainly local effects. They are therefore probably of minor importance from the perspective of sustainable development. If mining is done in agricultural areas, it can imply serious problems for these areas. Leakage of metals from mines and overburden can also imply long-term effects on the local environment.

Emissions of metals to the environment can occur all along the chain from the cradle to the grave. Emissions from the production system have historically increased with increased production during industrialization. Fortunately, the environmental restrictions introduced in later years have drastically reduced these point emissions to water and air from the production system. Instead, today, major emissions of metals to the environment in modern industrial systems tend to emanate from the consumption phase of the goods and not from their production.

There is a huge range in consumption losses between various types of use of metals. We have uses of metals that are intrinsically dissipative in their character. In chemical uses especially, metals are spread intentionally either already as products or in their uses as in, for example, paints and biocides. However, there are also intentional losses involved in metal uses, such as the lead used in ammunition. Losses from wear and tear or corrosion of products also vary considerably. For example, use of copper that give rise to emissions include, copper used outdoors and exposed to weathering as in roofing and facing materials, copper exposed to liquid flows as in tap-water systems and heat exchangers and copper in braking pads. The dissipation of the metals are concentrated to the places where the metals are used, that is mainly in towns and villages and where our industry and infrastructure are located. Locally the emissions to soil and water can be very high. However, for metals, the major system losses tend to emanate, not from direct emission to the ecosphere, but from *lack of recycling*. System losses mean metals in the technosphere that are taken out of use but are then are not recycled such as flows to deposits through waste-handling or materials simply left behind when no longer in service. The copper flow illustrates this. Large flows of copper recovered by the waste-handling system are not recycled, but are ultimately deposited in land-fills. A lot of copper in cables laid down in the ground, for example, is not recovered when the cables are taken out of service.

When recovered metal is of suitable quality, today's production technology often makes it possible to keep a very closed metal system, which can be exemplified by the lead system. This is also underscored by the fact that secondary production of metals often has much less specific loss than the corresponding primary production.

Potentially extractable metal ore deposits are suffering from various degrees of scarcity. Extraction is coupled to extensive manipulation and the intensive and often dissipative use of metals has led to severe contamination of the environment and threats to human health. Certain metals that are scarce in nature are not scarce in society. The relatively large use of many of the scarce heavy metals compared to natural turnover has an important implication: societal use of these metals has a large potential for producing substantially increased concen-trations of them in the ecosphere. Limited assimilative capacity in natural systems sets restrictions on the uncontrolled emissions of these metals. Contamination by heavy metals has also been a serious environmental problem so far during industrialization. The light metals are in a better position in that their societal use is small compared to natural turnover.

Metals can be separated in two main groups, abundant and scarce, on the basis of their abundance in the Earth's crust. The *abundant* metals are those that individually make up at least or almost 0.1 per cent by weight of the Earth's crust. There are very few such metals: iron and the light metals aluminium, magnesium and titanium and then, at almost 0.1 per cent, manganese. All other metals occur in much lower concentrations, near to 0.01 per cent and less, and are categorized as geochemically scarce metals.

The abundant metals are available in increasing amounts in lower grade down to the common rock, from which they can be mined directly. It is argued therefore, that society will never experience a sudden scarcity of these.

All metals are mined from ores rich in specific separate minerals containing metals. The ores are ground and the metal-bearing minerals are separated and concentrated before metallurgical treatment in which the metals are extracted from the minerals. In the Earth's crust, however, the scarce metals are very seldom concentrated in separate minerals, but most often are found, in small concentrations, stochastically distributed as substitutes for other elements in the minerals of ordinary rock. It is not possible to grind these minerals to separate specific atoms or molecules. Instead the metallurgical process has to treat all of the ordinary rock, which make the metal practically unavailable. This has been called the 'mineralogical barrier'. It has been estimated that not more than one in 104 to 105 of the total amount of each metal is located in a separate mineral. This can give a rough estimate of the ultimately recoverable amounts.

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