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Concise Environmental Engineering

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Contents

Preface

Environmental engineering is the application of science and engineering principles to protect and utilise natural resources, control environmental pollution, improve environmental quality to enable healthy ecosystems and comfortable habitation of humans. It is based on multiple disciplines including geology, hydrology, biology, chemistry, physics, medicine, engineering, management, economics, law, etc. Environmental engineering involves water supply, pollution control, recycling, waste (solid and liquid) disposal, radiation protection, industrial hygiene, environmental sustainability, and public health. This is an introductory book on environmental engineering and written for undergraduate students in civil and environmental engineering, chemical engineering, environmental science and geography. The aim of this book is to provide a concise and comprehensive coverage on environmental engineering. The book content covers the fundamental concepts/theories and their applications in environmental engineering. The key subjects include environment (natural and built environments), ecosystems (energy flow, nutrient cycles, biodiversity and ecosystem services), sustainability (key issues and activities), remote sensing of environment (electromagnetic radiation, sensors, data process and applications), environmental risk (hazards, risk perception, risk assessment, risk management, and environmental impact assessment), water supply (demand, availability, treatment, distribution and wastewater), water pollution (pollutants, pollution indicators, wastewater treatment, modelling and standards), solid waste (sources and waste system), air pollution (composition, structure, pollutants, emission control, modelling and forecasting), noise pollution (sources, properties, perception, measurement, health effects and noise control), climate change (observation, mechanisms, modelling, impact, mitigation and adaptation).

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1 Introduction

1.1 Environment

The 'Environment' has different meanings in different disciplines. In environmental engineering, the environment is where we live. It is divided into two types: natural environment and built environment. The natural environment encompasses all living and non-living things occurring naturally in the area (Figure 1.1). The built environment refers to the human-made surroundings that provide the setting for human activity (e.g., buildings, parks, cities and supporting infrastructure such as transport, water supply and energy supply) as shown in Figure 1.2. Modern remote sensing technology has made it easy for us to explore the natural and built environment in our surrounding areas and online mapping tools such as Google Earth are convenient facilities for us to view anywhere on the Earth (even to view many challenging places by foot such as the Everest). It should be noted that nowadays it is difficult to find absolutely natural environments (i.e., the wilderness, that has not been modified by human activity), and it is common that the naturalness varies in a scale, from ideally 100% natural in one extreme to 0% natural in the other (e.g., intensive farmland).

Figure 1.1 Natural environment, the Peak District national park, England (Google Earth)

Figure 1.2 Built environment, Bristol, England (Google Earth)

There are four spheres on the Earth that are of interest to environmental engineering, which are referred to as the lithosphere (the rigid outermost shell of the earth), the hydrosphere (water on, under, and over the surface of the Earth), the atmosphere (a layer of gases surrounding the Earth), and the biosphere (sum of living organisms on the Earth). They are combined to become the ecosphere and can be remembered easily as corresponding to rocks, water, air, and life.

1.2 Human and Environment

Human society and the environment interact with each other. Human impacts (i.e., anthropogenic impacts) on the environment refer to the impacts of human activities on biophysical environments, biodiversity and other resources. Those activities include agricultural practices (deforestation, genetically modified food, agricultural chemicals, soil degradation, agricultural plastics), fishing (overfishing, ecological disruption, by-catch), irrigation (soil salination, reduced river discharge, evaporation, withdraw of groundwater, drainage), livestock production (pollution, fossil fuels, water and land consumption), energy industry (climate change, biofuel use, fossil fuel use, electricity generation, renewable energy), manufacturing (cleaning agents, nanotechnology, paint, pesticides, pharmaceuticals and personal care products), mining (erosion, sinkholes, loss of biodiversity, contamination of soil, contamination of groundwater and surface water), transport (use of fossil fuels, air pollution, emission of carbon dioxide, traffic congestion, invasion of natural habitat and agricultural lands).

On the other hand, the natural environment and built environment can also affect human health. The World Health Organization defines environmental health as those aspects of the human health and disease that are determined by factors in the environment. The impacts of environment on human health include both the direct pathological effects of chemicals, radiation and some biological agents, and the indirect effects on health and well being of the broad physical, psychological, social and cultural environment (e.g., housing, urban development, land use and transport).

1.3 Environmental Engineering

Environmental engineering is the application of science and engineering principles to protect and utilise natural resources, control environmental pollution, improve environmental quality to enable healthy ecosystems and comfortable habitation of humans. It is based on multiple disciplines including geology, hydrology, biology, chemistry, physics, medicine, engineering, management, economics, law, etc. Environmental engineering activities involve water supply, waste water management, solid waste management, air pollution control, noise pollution control, radiation protection, environmental sustainability, public health issues, environmental impact assessment, hazardous-waste management, treatment of contaminated land, hazard prevention and mitigation, climate change adaptation and mitigation, renewable energy, etc. At many universities, environmental engineering programs follow either civil engineering or chemical engineering in engineering faculties with a diverse subject such as hydrology, water resources management, bioremediation, water treatment plant design, environmental chemistry, advanced air and water treatment technologies and separation processes.

1.4 The Topics Covered

This is an introductory book on environmental engineering and written for undergraduate students in civil and environmental engineering, chemical engineering, environmental science and geography. The aim of this book is to provide a concise and comprehensive coverage on environmental engineering that is easy to access through the web. The book content covers the fundamental concepts/theories and their applications in environmental engineering. The key subjects include environment (natural and built environments), ecosystems (energy flow, nutrient cycles, biodiversity and ecosystem services), sustainability (key issues and activities), remote sensing of environment (electromagnetic radiation, sensors, data process and applications), environmental risk (hazards, risk perception, risk assessment, risk management, and environmental impact assessment), water supply (demand, availability, treatment, distribution and wastewater), water pollution (pollutants, pollution indicators, wastewater treatment, modelling and standards), solid waste (sources and waste system), air pollution (composition, structure, pollutants, emission control, modelling and forecasting), noise pollution (sources, properties, perception, measurement, health effects and noise control), climate change (observation, mechanisms, modelling, impact, mitigation and adaptation).

Environmental engineering is broad with many parts of its contents changing fast with time. Further reading materials and web links are provided for readers to explore the interested topics in details and keep the domain knowledge up-to-date.

Further reading materials

Kiely, G, 1997, Environmental Engineering, McGraw-Hill, England
Mihelcic, J.R. and Zimmerman, J.B., 2010, Environmental Engineering, John Wiley & Sons, Inc
Wikipedia, 2012, 'Human impact on the environment', 'Environment', 'Environmental Engineering' http://en.wikipedia.org/wiki

2 Ecosystems

An ecosystem is a community of living (biotic) organisms (plants, animals and microbes) in conjunction with the nonliving components (abiotic) of their environment (air, water and mineral soil), interacting as a system. Ecosystems are a biological community and its physical environment, and come in various sizes from limited spaces to the entire planet. Ecosystems are dynamic with networks of interactions among organisms, between organisms and their environment. They are linked together through nutrient cycle and energy flow. Ecosystems are controlled both by external factors (climate, the parent material which forms the soil and topography) and internal factors (decomposition, root competition or shading, disturbance, succession and types of species).

Ecosystems provide a variety of goods and services to human society. It is important for environmental engineers to recognise and understand a wide range of ecosystem services in environmental engineering activities (e.g., in order to meet the drinking water standard, it may be more cost-effective for a water utility to invest in natural capital to improve the ecosystems of water sources than building an expensive new water filtration plant).

2.1 Energy Flow

Living organisms require two things from the environment: energy to provide power and nutrients to provide substance. Energy flow, also called the calorific flow, refers to the flow of energy through a food chain. The Sun is responsible for virtually all of the Earth' energy, which constantly gives the planet energy in the form of light while it is eventually used and lost in the form of heat throughout the trophic levels of a food web. The flow of energy in an ecosystem is an open system (i.e., it does not cycle and is converted to heat and lost for useful purposes forever).

The trophic (derived from the Greek referring to food) level of an organism is the position it occupies in a food chain. Based on the way to get food, organisms are classified as producers, consumers and decomposers. ***Producers*** (autotrophs) are typically plants or algae that do not usually eat other organisms, but pull nutrients from the soil or the ocean and manufacture their own food using photosynthesis powered by solar energy. An exception occurs in deep-sea hydrothermal ecosystems with no sunlight and chemosynthesis is used by organisms to make food. Since they are at the lowest trophic level, they are called primary producers. Higher up on the food chain, ***consumers*** (heterotrophs) are animals which cannot manufacture their own food and need to consume other organisms. Animals that eat primary producers (like plants) are called herbivores and animals that eat other animals are called carnivores, and animals that eat both plant and other animals are called omnivores. ***Decomposers*** (detritivores, such as bacteria and fungi) break down dead plants and animals and their wastes as energy and nutrients into the ecosystem for recycling.

There are five trophic levels. Decomposers are often left off food webs and trophic levels, but if included, they mark the end of a food chain.

Level 1: Plants and algae are primary producers
Level 2: Herbivores are primary consumers
Level 3: Carnivores are secondary consumers if they eat herbivores
Level 4: Carnivores are tertiary consumers if they eat other carnivores
Level 5: Apex predators are at the top of the food chain if they have no predators

A general energy flow in ecosystems starts with fixation of solar energy by photoautotrophs (i.e., primary producers). Primary consumers (i.e., herbivores) absorb most of the stored energy in the plant through digestion, and transform it into the form of energy they need through respiration. The received energy is stored as body mass with some converted to body heat radiated away and some lost by the expulsion of undigested food via excretion or regurgitation. Secondary consumers (carnivores) then consume the primary consumers and absorb the energy embodied in the primary consumers through the process of digestion. As with primary consumers, some energy is lost from the system. There may be higher level consumers to repeat the processes further on. A final link in the food chain is decomposers which break down the organic matter of the dead consumers (at all levels) and the undigested food excreted by the consumers, and release nutrients into the environment.

Energy transfer between trophic levels is generally inefficient with about 90% energy lost for each transfer. Generally, primary consumers get about 10% of the energy produced by autotrophs, while secondary consumers get 1% and tertiary consumers get 0.1%. This means the top consumer of a food chain receives the least energy, as a lot of the food chain's energy has been lost to the environment instead of being absorbed between trophic levels. This loss of energy at each level limits typical food chains to only four to six links.

2.2 Nutrient Cycles

Nutrient cycle is the movement and exchange of organic and inorganic matter back into the production of living matter. It is a part of larger biogeochemical cycles involving macros nutrients (such as carbon, nitrogen, oxygen, phosphorus, and sulphur, etc.) and micros nutrients (iron, copper, sodium, etc.) —the important chemicals used as nutrients in ecosystems by living organisms. In contrast to the energy flow, the nutrient flow is a part of a closed system and these chemicals are recycled and replenished constantly instead of being lost. The chemicals are sometimes held for long periods of time in one place called a reservoir (e.g., coal deposits with carbon), or are held for only short periods of time in exchange pools (e.g., plants and animals). In this section, only some key macros nutrients are described because they play an essentials role in ecosystems.

2.2.1 Oxygen Cycle

The Oxygen cycle describes the movement of oxygen within its three main reservoirs: biosphere (the smallest of the three reservoirs with an average residence time of 50 years), atmosphere (it is 100 times of the oxygen mass in the biosphere with an average residence time of 4500 years), and lithosphere (it is 200 times of the oxygen mass in the atmosphere, the largest reservoir with an average residence time of 500 million years). Therefore, 99.5% of oxygen is stored in the lithosphere, 0.5% in the atmosphere and only 0.005% in the biosphere.

The gain of oxygen in the atmosphere is driven mainly by the Sun through photosynthesis (55% by land plants and 45% by ocean phytoplankton). The losses of atmospheric oxygen are mainly by aerobic respiration at 77% (consumed by animals and bacteria), microbial oxidation 17%, fossil fuel combustion 4%, and photochemical oxidation 2%.

2.2.2 Carbon Cycle

The carbon cycle describes the movement of carbon within its main reservoirs: atmosphere, hydrosphere (oceans), lithosphere and biosphere. The lithosphere has the largest store of carbon (it collects its carbon from the atmosphere by the accumulated dead life form and releases its carbon by either slow geological movement or fast combustion as fuel by humans). Oceans are the 2nd largest reservoir for carbon (mainly in inorganic form). The biosphere on land has a much smaller carbon store (a small fraction of that in oceans) and the atmosphere has the smallest carbon store (about 1/3 of the biosphere). The ocean plays a vital role in the Earth's carbon cycle, but it is the increasing carbon in the atmosphere that is of major concern in modern times due to the burning of fossil fuels (Figure 2.1).

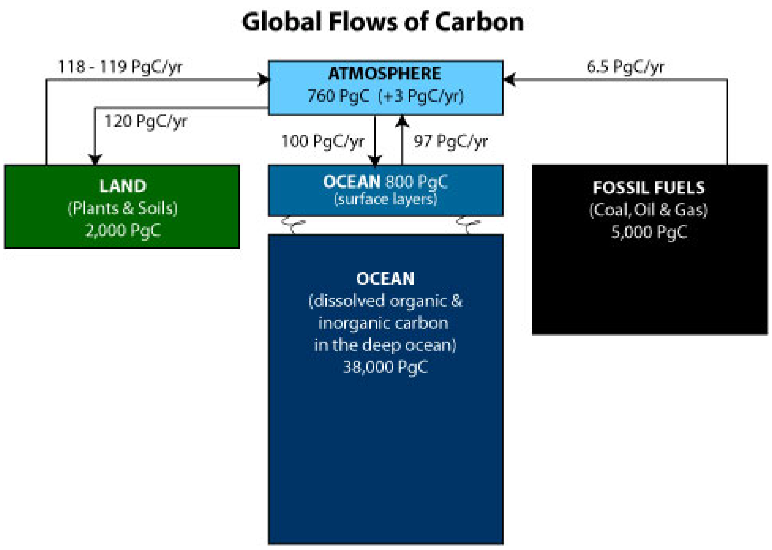

Figure 2.1 Carbon Cycle (NASA, http://science.nasa.gov)

In the past two centuries, human activities have seriously altered the global carbon cycle, most significantly in the atmosphere. Carbon in the Earth's atmosphere exists in two main forms: carbon dioxide and methane. Both of these gases are partially responsible for the greenhouse effect. Methane produces a large greenhouse effect per volume as compared to carbon dioxide, but it exists in much lower concentrations and is more short-lived than carbon dioxide, making carbon dioxide the more important greenhouse gas of the two. The concentration of carbon dioxide in the Earth's atmosphere is approximately 392 ppmv (parts per million by volume) as of 2011 and rose by 2.0 ppmv/yr (Figure 2.2). The current concentration is substantially higher than the 280 ppmv concentration in preindustrial times, with the increase largely attributed to anthropogenic sources. There is an annual fluctuation of about 3–9 ppmv which roughly follows the Northern Hemisphere's growing season.

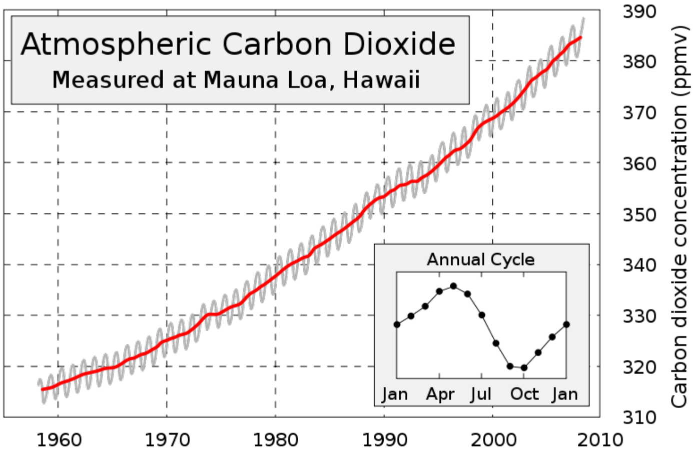

Figure 2.2 Atmospheric CO_2 concentrations as measured at Mauna Loa Observatory (Wikipedia 'Keeling Curve')

In the biosphere, carbon is mainly absorbed in the form of carbon dioxide by plants. Carbon is also released from the biosphere into the atmosphere in the course of biological processes. Aerobic respiration converts organic carbon into carbon dioxide and anaerobic respiration converts it into methane. After respiration, both carbon dioxide and methane are typically emitted into the atmosphere. Organic carbon is also released into the atmosphere via burning. While organic matter in animals generally decays quickly, releasing much of its carbon into the atmosphere through respiration, carbon stored as dead plant matter can stay in the biosphere for as much as a decade or more. Different plant types of plant matter decay at different rates (for example, woody substances retain their carbon longer than soft, leafy material). Active carbon in soils can stay sequestered for up to a thousand years, while inert carbon in soils can stay sequestered for more than a millennium.

2.2.3 Nitrogen Cycle

The nitrogen cycle is the process by which nitrogen is converted between its various chemical forms (Figure 2.3). Nitrogen is required to biosynthesise basic building blocks of plants, animals and other life forms (e.g., nucleotides for DNA and RNA and amino acids for proteins). Important processes in the nitrogen cycle include fixation, ammonification, nitrification, and denitrification.

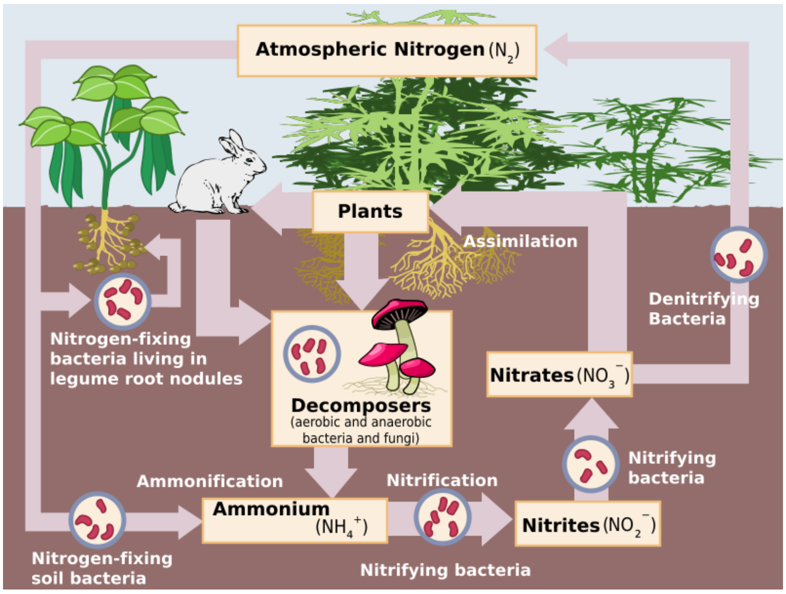

Figure 2.3 Nitrogen cycle (Wikipedia 'Nitrogen cycle')

Although 78% of the air is nitrogen, atmospheric nitrogen (N_2) must be processed or "fixed" into ammonia (NH_3) to be used by plants. Some fixation occurs in lightning strikes, but most fixation is done by free-living or symbiotic bacteria. When a plant or animal dies, or an animal expels waste, the initial form of nitrogen is organic. Bacteria (or fungi in some cases) convert the organic nitrogen within the remains back into ammonium (NH4+), a process called ammonification or mineralisation. Nitrification is a two-step process with the biological oxidation of ammonia (with oxygen) into nitrite followed by the oxidation of these nitrites into nitrates (by two types of organisms that exist in most environment). Nitrification is important in agricultural systems, where fertiliser is often applied as ammonia. Denitrification is the reduction of nitrates back into the largely inert nitrogen gas (N_2), completing the nitrogen cycle. Nitrification (together denitrification) also plays an important role in the removal of nitrogen from municipal wastewater.

Human impact on the nitrogen cycle is diverse. Agricultural and industrial nitrogen inputs to the environment currently exceed inputs from natural nitrogen fixation and the global nitrogen cycle has been significantly altered over the past century. Human activities such as fossil fuel combustion, use of artificial nitrogen fertilizers, and release of nitrogen in wastewater have dramatically altered the global nitrogen cycle.

2.2.4 Phosphorus Cycle

The phosphorus cycle describes the movement of phosphorus through the lithosphere, hydrosphere, and biosphere. Unlike many other biogeochemical cycles, the atmosphere does not play a significant role in the movement of phosphorus, because phosphorus does not enter the atmosphere and remains mostly as solid salts on land (in rock and soil minerals). Weathering of rocks carries these phosphates to terrestrial habitats. Plants absorb phosphates from the soil and then are consumed by herbivores that in turn may be consumed by carnivores. After death, the animal or plant decays to return phosphates to the soil. Runoff may carry them back to the ocean to be reincorporated into rock. The processes that move them through the soil or ocean are very slow, making the phosphorus cycle overall one of the slowest biogeochemical cycles.

Phosphorus is an essential nutrient for plants and animals in the form of ions and is a limiting nutrient for aquatic organisms. Human interference in the phosphorus cycle occurs by overuse or careless use of phosphorus fertilisers, which results in phosphorus as pollutants in bodies of water with eutrophication consequences.

2.2.5 Sulphur Cycle

The sulphur cycle is similar to the nitrogen cycle in that microbial processes control which form of sulphur appears in the natural environment. The most oxidised form of sulphur is sulphate which is the form most readily assimilated by plants to be reduced into organic sulphur. Sulphur is a key component in proteins, amino acids and B vitamins of plants and animals. Once plants and animals die, bacteria turn organic sulphur into reduced sulphide (H_2S) and then into sulphate to complete the cycle.

2.3 Eutrophication

Eutrophication (Greek: eutrophia—adequate nutrition) is the ecosystem response to excess nutrients that stimulate excessive plant growth. The nutrients are mainly nitrates and phosphates which are human-caused (e.g., fertiliser, untreated sewage effluent) or natural (depositional environments). Excessive plant growth and decay favour simple algae and plankton over other more complicated plants and cause a severe reduction in water quality Enhanced growth of aquatic vegetation or phytoplankton and algal blooms disrupts normal functioning of the ecosystem, causing a variety of problems such as a lack of oxygen needed for fish and shellfish to survive. The water becomes cloudy, typically coloured in a shade of green, yellow, brown, or red (Figure 2.4). Some algal blooms are toxic to plants and animals, and interfere with drinking water treatment.

The nutrients come from two types of sources: point source (a single identifiable source) and nonpoint source (diffuse sources varying spatially). Point sources are relatively easy to regulate compared with nonpoint sources. Nutrients from human activities tend to travel from land to either surface water or ground water. Nitrogen in particular moves through storm drains, sewage pipes, and other forms of surface runoff. Modern agriculture often involves the application of nutrients onto fields in order to maximise production. However, farmers frequently apply more nutrients than the amount taken up by crops or pastures. Nutrients tend to accumulate in soils and remain there for years. Phosphorus lost to surface waters increases linearly with the amount of phosphorus in the soil. Nitrogen, similarly, has a turnover time of decades or more. Ploughing in agriculture and other developments are activities that contribute most to nutrient loading. In addition, nitrogen is released into the air because of ammonia volatilisation and nitrous oxide production. The combustion of fossil fuels is a large human-initiated contributor to atmospheric nitrogen pollution. Atmospheric deposition (e.g., in the form of acid rain) can also affect nutrient concentration in water. In modeling eutrophication, the rate of water renewal plays a critical role because stagnant water is able to collect more nutrients. The drying of wetlands could also cause an increase in nutrient concentration and subsequent eutrophication blooms.

Figure 2.4 Example of lake eutrophication (Taiho Lake)

2.4 Biodiversity

Biodiversity is the degree of variation of life forms at all levels of biological systems (i.e., molecular, organismic, population, species and ecosystem) and is used to measure the health of ecosystems. Biodiversity is the result of 3.5 billion years of evolution. The fossil record suggests that the last few million years feature the greatest biodiversity in history based on fossil record analysis (Figure 2.5). Since life began on the Earth, five major mass extinctions and several minor events have led to large and sudden drops in biodiversity. It is found that biodiversity appears to increase continually in the recent Earth history. However, most biologists agree that the period since human emergence is part of a new mass extinction, named the Holocene extinction event, caused primarily by the impact humans on the environment via the acronym HIPPO (Habitat destruction, Invasive species, Pollution, human over Population, and Over-harvesting).

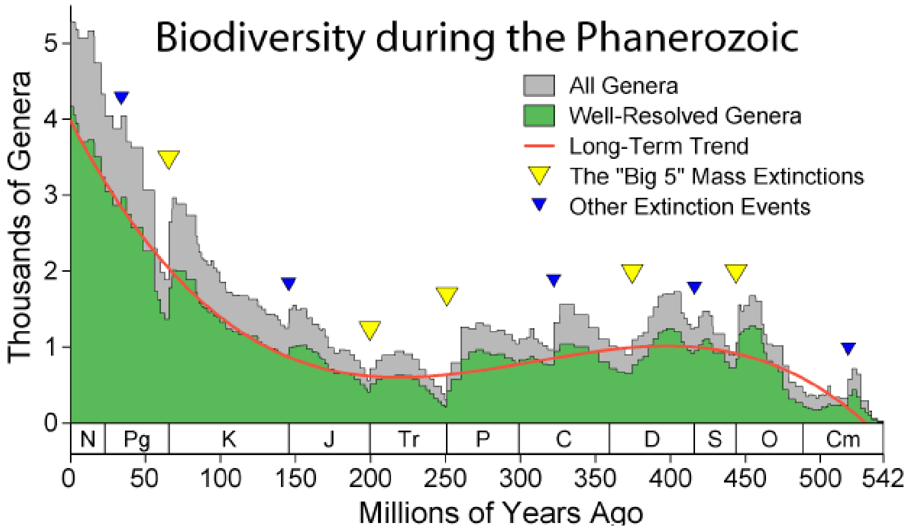

Figure 2.5 Apparent marine fossil diversity in the last 540 million years (Wikipedia 'Biodiversity')

Biological diversity can be quantified in many different ways. The two main factors taken into account when measuring diversity are richness and evenness. Richness is a measure of the number of different kinds of organisms in a particular area. The more species present in a sample, the 'richer' the sample is. Evenness is a measure of the relative abundance of the different species making up the richness of an area. In practice, several diversity indices have been used to measure biodiversity, such as Shannon index, Simpson index, etc. Accurately measuring biodiversity can be difficult.

Biodiversity is not evenly distributed because of variations in temperature, precipitation, altitude, soils, geography and the presence of other species. Generally, there is an increase in biodiversity from the poles to the tropics (i.e., latitudinal gradient in species diversity) mainly due to the greater mean temperature at the equator compared with that of the poles. There are also biodiversity hotspots around the world which are regions with a high level of endemic species (the majority are forest areas and most are located in the tropics).

Human society benefits from healthy biodiversity which supports ecosystem services including air quality, climate (e.g., CO_2 sequestration), water purification, pollination, and prevention of erosion. There are many measures that could be used to protect and restore rich biodiversity, such as removal of exotic species, reintroduction of the lost species, biodiversity banking, reduction of pesticide usage, wildlife corridors, resource allocation, etc.

2.5 Ecosystem Services

Ecosystem services are the benefits to human society from a multitude of resources (e.g., food, water) and processes (e.g., decomposition of wastes) supplied by natural ecosystems. Ecosystem services are divided into four categories: 1) provisioning services: food, water, timber, minerals, pharmaceuticals, biochemicals, industrial products, energy (hydropower, biomass fuels); 2) regulating services: control of climate by carbon sequestration, waste decomposition and detoxification, purification of water and air, pest and disease control, erosion prevention; 3) supporting services: nutrient dispersal and cycling, seed dispersal, crop pollination, primary production; 4) cultural services: cultural, intellectual and spiritual inspiration, recreation, scientific discovery.

Society is increasingly dependent on ecosystem services which are not only limited but also threatened by human activities. Understanding of ecosystem services requires a sound understanding on underlying principles, and interactions of organisms and the environment. Since the scales at which these entities interact can vary from microbes to landscapes, milliseconds to millions of years, it is a major challenge to describe and predict energy and material flow in the ecosystems. The research steps involved include 1) identification of ecosystem service providers (ESPs) – species or populations that provide specific ecosystem services – and characterisation of their functional roles and relationships; 2) determination of community structure aspects that influence how ESPs function in their natural landscape; 3) assessment of key environmental (abiotic) factors influencing the provision of services; and 4) measurement of the spatial and temporal scales ESPs and their services operate on.

Many efforts to inform decision-makers of current versus future costs and benefits involve organising and translating scientific knowledge to economics, which articulate the consequences of different choices in comparable units of impacts on human well-being. The six major methods for valuing ecosystem services in monetary terms are: 1) avoided cost: services allow society to avoid costs that would have been incurred in the absence of those services (e.g. wastewater treatment by wetland); 2) replacement cost: services could be replaced with man-made systems (e.g. restoration of a catchment costs less than the construction of a water purification plant); 3) factor income: services provide for the enhancement of incomes (e.g. improved water quality increases the commercial take of a fishery and improves the income of fishers); 4) travel cost: service demand may require travel, whose costs can reflect the implied value of the service (e.g. value of ecotourism experience is at least what a visitor is willing to pay to get there); 5) hedonic pricing: service demand may be reflected in the prices people will pay for associated goods (e.g. coastal housing prices exceed that of inland homes); 6) contingent valuation: service demand may be elicited by posing hypothetical scenarios involving some valuation of alternatives (e.g. visitors willing to pay for increased access to national parks).

Several newly developed tools and methodologies may help evaluate and assess ecosystem services. These include 'Our Ecosystem', the Corporate Ecosystem Services Review (ESR), Artificial Intelligence for Ecosystem Services (ARIES), the Natural Value Initiative (NVI) and InVEST (Integrated Valuation of Ecosystem Services & Tradeoffs). The valuation of ecosystem services helps policy implementation and management. Human society suffers from the so-called 'tragedy of the commons' and effective administration of common pool resources is crucial to prevent further degradation of the ecosystems. Considering options must balance present and future human needs, and decision-makers must frequently work from valid but incomplete information. Payment and trading of services is an emerging solution where one can acquire credits for activities such as sponsoring the protection of carbon sequestration sources or the restoration of ecosystem service providers.

Further reading materials

Kiely, G, 1997, Environmental Engineering, McGraw-Hill, England
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Wikipedia, 2012, 'Carbon cycle', 'Nitrogen cycle', 'Oxygen cycle', 'Human impact on the nitrogen cycle', 'Phosphorus cycle', 'Trophic level', 'Ecosystem services', 'Biodiversity', 'Diversity index'
http://en.wikipedia.org/wiki

3 Sustainability

3.1 What is Sustainability?

Sustainability is the capacity to endure. For human society, "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". It requires the reconciliation of environmental, social equity and economic demands - the "three pillars" of sustainability or (the 3 E's) as shown in Figure 3.1. The three pillars are the "triple bottom line" served as a common ground for numerous sustainability standards and certification systems in recent years.

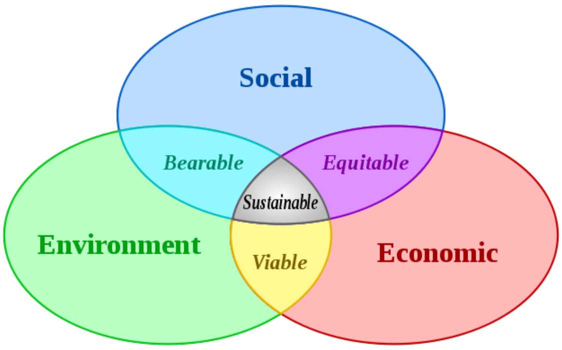


Figure 3.1 Sustainability and its three pillars (Wikipedia 'Sustainability')

Sustainability measurement is the metrics used as the quantitative basis for the informed management of sustainability. Measurement of sustainability is very diverse and still evolving, including resource use like ***life cycle assessment***, consumption like the ***ecological footprint*** and quality of environmental governance like the ***Environmental Performance Index***.

A life-cycle assessment (LCA, also known as life-cycle analysis) is a technique to assess environmental impacts associated with all the stages of a product's life from-cradle-to-grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). LCA can help avoid a narrow outlook on environmental concerns by compiling an inventory of relevant energy and material inputs and environmental releases, evaluating the potential impacts associated with identified inputs and releases and interpreting the results to help more informed decision makings.

The ecological footprint is a measure of human demand on the Earth's ecosystems. Ecological footprint analysis compares human demand on the nature with the biosphere's ability to regenerate resources and provide services. It does this by assessing the biologically productive land and marine area required to produce the resources a population consumes and absorb the corresponding waste, using prevailing technology. The tool can inform policy by examining to what extent a nation uses more (or less) than is available within its territory. The footprint can also be a useful tool to educate people about carrying capacity and over-consumption, with the aim of altering personal behaviour. Carry capacity is linked to resources limitations and is the upper limit to population or community size imposed through environmental resistance. As described in the book 'The Limits to Growth', society in the past has 'evolved around the principle of fighting against limits rather than learning to live with them'. The ecological footprint helps people realise there is a limit to resources. Ecological footprints may be used to argue that many current lifestyles are not sustainable. Such a global comparison also clearly shows the inequalities of resource use on this planet (Figure 3.2).

The Environmental Performance Index (EPI) is a method of quantifying and numerically benchmarking the environmental performance of a country's policies. This index was developed from the Pilot Environmental Performance Index, first published in 2002, and designed to supplement the environmental targets set forth in the U.N. Millennium Development Goals. It considers water, air, productive natural resources, forestry, fisheries, agriculture, biodiversity, habitat and climate change.

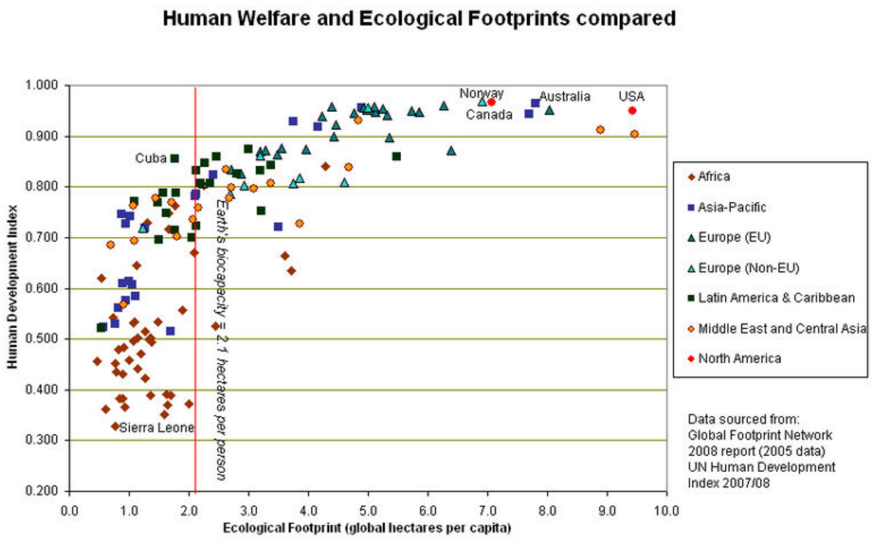


Figure 3.2 Ecological footprints for different countries
(The orange line indicates the available global hectare, Wikipedia 'Ecological footprint')

3.2 Issues Relevant to Sustainability

3.2.1 Population Growth

The current global population of 7 billion (2012) is expected to reach 9 billion by 2050 (Figure 3.3). The population growth is one of the grand challenges for sustainable development since an increasing population places additional strain on natural resources. Currently, most population growth occurs in the developing world and population is more or less stagnant in the industrialised world. The economic development is linked with the quality of life. As the pattern of population growth shows, the rate of population growth has a negative correlation to the economic development. Therefore, population growth could be stabilised by improving quality of life. However, improvement in quality of life and economic development has closely linked with enhanced consumption and associated depletion and environmental degradation.

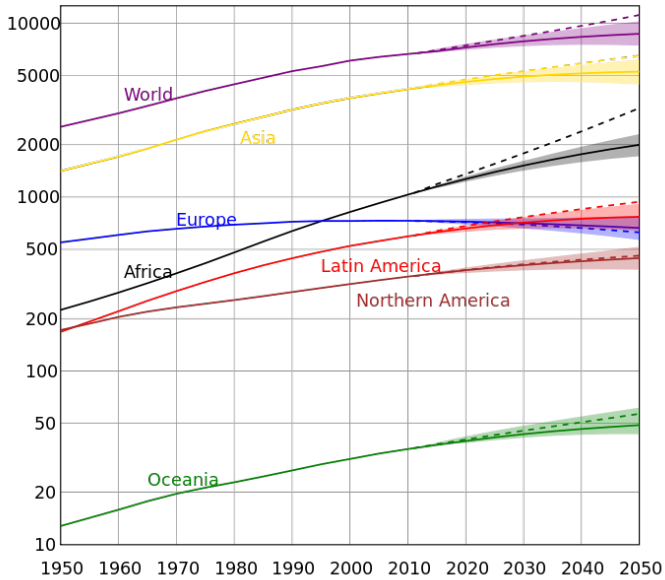


Figure 3.3 Estimates of population evolution in different continents between 1950 and 2050 (Source: UN, wikipedia 'World population')

3.2.2 Urbanisation

Urbanisation is the physical growth of urban areas as a result of rural migration. Currently, there are more people living in urban areas than in rural areas. The trend of urbanisation will continue in the foreseeable future (Figure 3.4). Historical migration of human populations begins with the movement of Homo erectus out of Africa across Eurasia about a million years ago. Homo sapiens appear to have occupied all of Africa about 150,000 years ago, moved out of Africa 70,000 years ago, and had spread across Australia, Asia and Europe by 40,000 years BC. Early humans migrated due to many factors such as changing climate and landscape and inadequate food supply. While the pace of migration had accelerated since the 18th century (including the involuntary slave trade), it increased further in the 19th century. Nowadays, urbanisation is the major type of human migration.

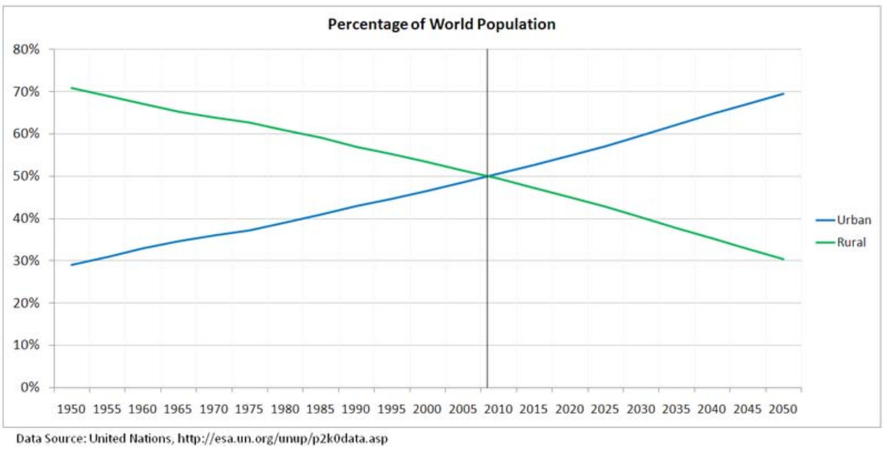


Figure 3.4 Percentage of World Population: Urban vs. Rural (the United Nations)

Cities are known to be places where money, services (e.g., hospitals, universities, theatres) and wealth are centralised. Businesses, which provide jobs and services, are more concentrated in urban areas. Many rural inhabitants come to the city for reasons of seeking jobs, fortunes and social mobility. In rural areas, it has traditionally been difficult to access modern facilities and farm living has always been susceptible to unpredictable environmental conditions (drought, flood or pestilence). Village culture in rural areas is characterised by common bloodlines, intimate relationships, and communal behaviour whereas urban culture is characterised by distant bloodlines, unfamiliar relations, and competitive behaviour. Pollution and lack of vegetation, especially trees, can cause urban areas to suffer from poor environment. Historically, many large European cities are divided into a 'good' west and a 'poor' east due to the prevailing south-west wind which carries coal smoke and other airborne pollutants downwind, making the western edges of cities preferable to the eastern ones.

3.2.3 Water

Water resources are useful or potentially useful sources of water. Uses of water include agricultural, industrial, household, recreational and environmental activities. Virtually all of these human uses require fresh water. 97% of the water on the Earth is salt water and only three percent is fresh water. Slightly over two thirds of fresh water is frozen in glaciers and polar ice caps. The remaining unfrozen fresh water is found mainly as groundwater, with only a small fraction present above ground or in the air (Figure 3.5).

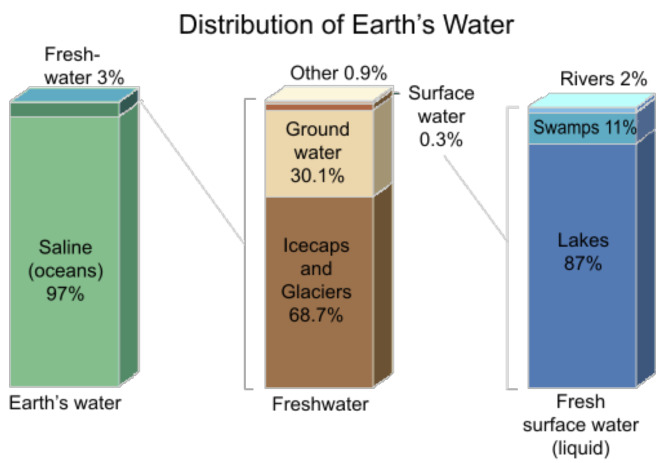


Figure 3.5 Water distribution on earth (Wikipedia 'Water resources')

The term "***water footprint***" is often used to refer to the amount of water used by an individual, community, business, or nation. It is defined as the total volume of freshwater used to produce the goods and services consumed by the individual or community or produced by the business. Water use is measured in water volume consumed (evaporated) and/or polluted per unit of time. A water footprint can be calculated for any well-defined group of consumers (e.g., an individual, family, village, city, province, state or nation) or producers (e.g., a public organisation, private enterprise or economic sector). The water footprint is a geographically explicit indicator, not only showing volumes of water use and pollution, but also the locations. A water footprint consists of three components: ***blue, green, and grey***. The blue water footprint is the volume of fresh water that evaporated from the global blue water resources (surface water and ground water) to produce the goods and services consumed by the individual or community. The green water footprint is the volume of water evaporated from the global green water resources (rainwater stored in the soil as soil moisture). The grey water footprint is the volume of polluted water that associates with the production of all goods and services for the individual or community. The latter can be estimated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains at or above agreed water quality standards.

However, the water footprint does not provide information on how the embedded water negatively or positively affects local water resources, ecosystems and livelihoods. ***Virtual water*** (also known as embedded water, embodied water, or hidden water) refers, in the context of trade, to the water used in the production of a good or service.

Fresh water is a renewable resource, yet the world's supply of clean, fresh water is steadily decreasing. Water demand already exceeds supply in many parts of the world and as the world population continues to rise, so too does the water demand. Water scarcity is a situation where there is insufficient water to satisfy normal human requirements, which are defined by the World Health Organisation as a water source with 20L/person/day within 1km distance. A country is defined as experiencing water stress when its annual water supplies drop below 1700m^3/person. If the annual water supplies drop below 1000 m^3/person, the country is defined as water scarce. Water is expected to be a source of both tension and cooperation in the future. There are more than 215 major rivers and 300 groundwater aquifers shared by two or more countries. Finding sustainable solutions to water infrastructure problems is a huge challenge for engineers.

3.2.4 Energy

In the context of human society, the word energy is used as a synonym of energy resources, and most often refers to substances like fuels, petroleum products and electricity in general. The use of energy has been a key in the development of the human society by helping it to control and adapt to the environment. Managing the use of energy is inevitable in any functional society. In the industrialised world the development of energy resources has become essential for agriculture, transportation, waste collection, information technology, communications that have become prerequisites of a developed society. The increasing use of energy since the Industrial Revolution has also brought with it a number of serious problems, some of which, such as global warming, present potentially grave risks to the world.

Primary energy is an energy form found in nature that has not been subjected to any conversion or transformation process. It is energy contained in raw fuels, and other forms of energy received as input to a system. Primary energy can be non-renewable or renewable. Examples of sources include nonrenewables (fossil fuels such as oil, coal, natural gas, and mineral fuels such as natural uranium) and renewable (solar, wind, water, biomass, geothermal). Primary energy sources are transformed in energy conversion processes to more convenient forms of energy (that can directly be used by society), such as electrical energy, refined fuels, or synthetic fuels such as hydrogen fuel. In the field of energetics, these forms are called energy carriers and correspond to the concept of "secondary energy" in energy statistics. Electricity is one of the most common energy carriers, being transformed from various primary energy sources such as coal, oil, natural gas, and wind.

3.3 Sustainability Activities

3.3.1 Green Engineering

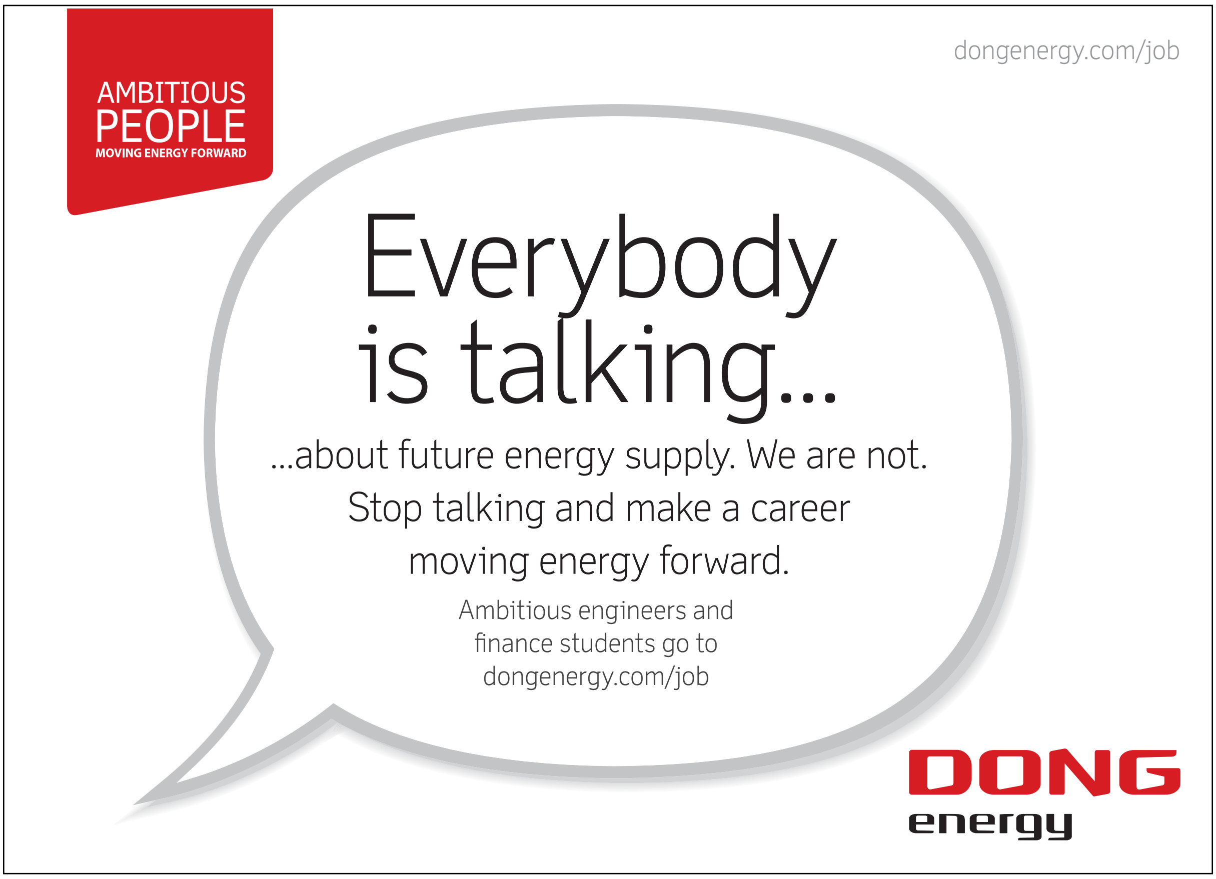
For engineers, sustainable engineering is the design of man-made systems to ensure the current uses of natural resources do not lead to diminished quality of life of future generations. For engineers, 'design' is the key word' here. Green engineering is to design, discover and implement engineering solutions with an awareness of potential benefits and problems in terms of environment, economy and society (three pillars of sustainability) throughout the design lifetime. The goal is to minimise adverse impacts (e.g., water use inefficiency, depletion of finite materials and energy resources, urban congestion, water and air pollution, degradation of environment) while simultaneously maximising benefits to the economy, society and environment.

The principles of green engineering as outlined by Anastas and Zimmerman) include

1. Inherent Rather Than Circumstantial (Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently nonhazardous as possible);
2. Prevention Instead of Treatment (It is better to prevent waste than to treat or clean up waste after it is formed);
3. Design for Separation (Separation and purification operations should be designed to minimise energy consumption and materials use);
4. Maximise Efficiency (Products, processes, and systems should be designed to maximise mass, energy, space, and time efficiency);
5. Output-Pulled Versus Input-Pushed (Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials);
6. Conserve Complexity (Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition);
7. Durability Rather Than Immortality (Targeted durability, not immortality, should be a design goal);
8. Meet Need, Minimise Excess (Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw);
9. Minimise Material Diversity (Material diversity in multicomponent products should be minimised to promote disassembly and value retention);
10. Integrate Material and Energy Flows (Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows);
11. Design for Commercial "Afterlife" (Products, processes, and systems should be designed for performance in a commercial "afterlife");
12. Renewable Rather Than Depleting (Material and energy inputs should be renewable rather than depleting).

3.3.2 Renewable Energy

Climate change concerns, coupled with high oil prices, peak oil, and increasing government support, are driving increasing renewable energy legislation, incentives and commercialisation. The incentive to use 100% renewable energy is gaining momentum among many countries. The first country to propose 100% renewable energy was Iceland, in 1998. Proposals have been made for Japan in 2003, and for Australia in 2011. Norway and some other countries have already obtained all of their electricity from renewable sources. A predicted growth for wind and solar energy is illustrated in Figure 3.6.



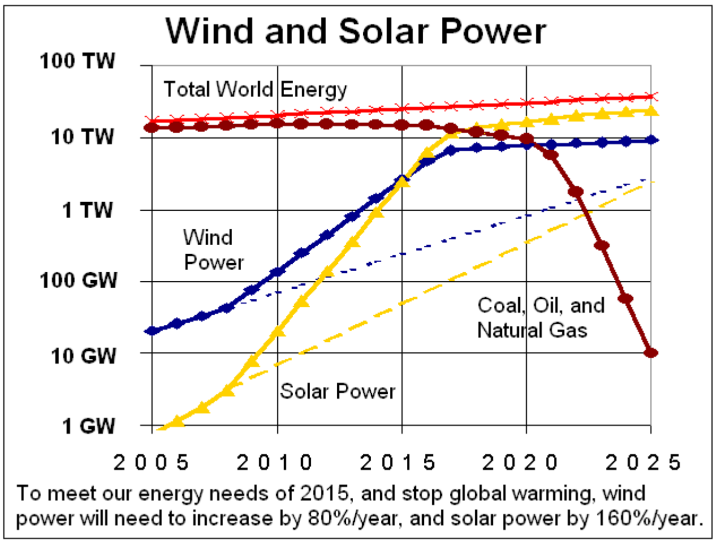


Figure 3.6 Growth of wind and solar power (Wikipedia 'Renewable energy')

In contrast to energy production, energy conservation refers to efforts made to reduce energy consumption. Energy conservation can be achieved through increased efficient energy use, in conjunction with decreased energy consumption and/or reduced consumption from conventional energy sources. In building designs, windows, walls, and floors are made to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer. This is called passive solar design or climatic design because, unlike active solar heating systems, it doesn't involve the use of mechanical and electrical devices. The key to designing a passive solar building is to best take advantage of the local climate. Elements to be considered include window placement and glazing type, thermal insulation, thermal mass, and shading. Passive solar design techniques can be applied most easily to new buildings, but existing buildings can be adapted or "retrofitted".

A zero-energy building (also known as a zero net energy (ZNE) building, Net-Zero Energy Building (NZEB), or Net Zero Building) is a popular term to describe a building with zero net energy consumption and zero carbon emissions annually. Zero energy buildings can be independent from the energy grid supply. Energy can be harvested on-site—usually through a combination of energy producing technologies like Solar and Wind—while reducing the overall use of energy with extremely efficient HVAC (heating, ventilation, and air conditioning) and Lighting technologies. The zero-energy design principle is becoming more practical to adopt due to the increasing costs of traditional fossil fuels and their negative impact on the planet's climate and ecological balance. A building approaching zero net energy use may be called a "near-zero energy building" or "ultra-low energy house". Buildings that produce a surplus of energy during a portion of the year may be known as "energy-plus buildings".

The built environment (buildings, roads, bridges and other infrastructures) requires a tremendous amount of energy, as well as water and other natural resources. ***Embodied Energy*** is the sum of all the energy required to produce goods or services, considered as if that energy is incorporated or 'embodied' in the product itself. The concept can be useful in determining the effectiveness of energy-producing or energy-saving devices. The embedded energy in concrete has a significant impact on construction energy flows. The transport of aggregates and cement to construction site accounts for more than 10 percent of the total embedded energy. In addition, production of 1 kg of Portland cement generates 1 kg of CO_2.

3.3.3 Resources Management

Human society development depends on natural resources (air, water, forest, minerals, etc.) because human beings must use and even exploit nature to survive and live. Sustainability implies that rather than competing for endless growth on a finite planet, development should improve quality of human life without necessarily having to consume more resources. Environmental resources management aims to ensure that ecosystem services are protected and maintained for equitable use by future human generations, and ecosystem integrity should be maintained as an end in itself by considering ethical, economic, and scientific (ecological) variables. Environmental resource management should identify the conflicting factors that may rise between meeting the needs and protecting the resources. Environmental resource management involves the management of all components of the biophysical environment, both living (biotic) and non-living (abiotic). This is due to the interconnection and interdependence amongst all living species and their habitats. The essential aspects of environmental resource management are ethical, economical, social and technological which provide for formulation of principles in making decisions. To achieve sustainable development with environmental resource management, sustainability principles should be adopted to include social and environmental accountability, long-term planning, a strong and shared vision a holistic focus, broad stakeholder engagement and justice, transparency, trust, and flexibility, etc. A good example on resources management is Integrated Water Resources Management (IWRM) which is a coordinated, goal-directed process for controlling the development and use of river, lake, ocean, wetland, and other water assets. Operationally, IWRM approaches involve applying knowledge from various disciplines as well as the insights from diverse stakeholders to devise and implement efficient, equitable and sustainable solutions to water and development problems. Water has many different uses (agriculture, industry, ecosystems, people and livelihoods) and demands coordinated action. An IWRM approach is an open, flexible process, bringing together decision-makers and all stakeholders to the table to set policy and make sound, balanced decisions in response to specific water challenges faced.

Technically, mathematical optimisation is a powerful tool for environmental engineers to manage resources problems. In mathematics, an optimisation problem is a search for the best solution from all feasible options. An objective function (either a cost function for minimisation or a utility function for maximisation) is set up to be optimised. There are many optimisation methods available for different optimisation problems. They include linear programming, integer programming, nonlinear programming, evolution algorithms, etc. For complex problems, multi-objective optimisation (also known as multi-criteria or multi-attribute optimisation) may be used to simultaneously optimise two or more conflicting objectives subject to certain constraints. For multi-modal optimisation problems, there could be several globally good solutions (the same cost function value). Obtaining all (or at least some of) the multiple solutions is the goal of a multi-modal optimiser. Both multi-objective and multi-modal problems are difficult to solve by traditional optimisation techniques and evolutionary algorithms are gaining popularity in dealing with those problems. This is because evolutionary algorithms optimise a set of solutions simultaneously, allowing computation of an approximation of the entire Pareto front in a single algorithm run. Although evolutionary algorithms are computationally intensive, modern computers have made those computation issues less a problem.

3.3.4 Pollution Control

Pollution is the introduction of contaminants into the natural environment with adverse changes (air pollution, water pollution, land pollution, etc). Pollutants can be either foreign substances or naturally occurring contaminants. Pollution control means the control of emissions and effluents into air, water or soil. Without pollution control, the waste products from consumption, heating, agriculture, mining, manufacturing, transportation and other human activities, whether they accumulate or disperse, will degrade the environment. In the hierarchy of controls, pollution prevention and waste minimisation are more desirable than other mitigating measures. In the field of land development, low impact development is a similar technique for the prevention of urban runoff. Pollution control activities include recycling, reusing, reducing, mitigating, preventing, compost, etc. Further details on pollutions are described in various chapters of this book.

3.3.5 Sustainable Agriculture

Sustainable agriculture is an integrated system of plant and animal production practices that will last over the long term. It is based on the study of relationships between organisms and their environment using principles of ecology. The benefits in sustainable agriculture include meeting human food and fibre needs, enhancing environmental quality and the natural resource base, making the most efficient use of non-renewable resources and on-farm resources, integrating natural biological cycles and controls, sustaining the economic viability of farm operations, and enhancing the quality of life for farmers and society as a whole.

When farmers grow and harvest crops, they remove some of nutrients from the soil. Without replenishment, land suffers from nutrient depletion and becomes either unusable or suffers from reduced yields. In practice, farmers tend to over-apply synthetic fertiliser or animal manures, which can improve productivity but can pollute nearby rivers and coastal waters (eutrophication). Many farming practices can cause long-term damage to soil including excessive tillage (leading to erosion). Soil erosion is fast becoming one of the world's greatest problems. The phenomenon is being called Peak Soil as present large scale factory farming techniques are jeopardising humanity's ability to grow food in the present and in the future. Without efforts to improve soil management practices, the availability of arable soil will become increasingly problematic. Availability of water is crucial for sustainable agriculture. In some areas, sufficient rainfall is available for crop growth, but many other areas require irrigation. However, improper irrigation without adequate drainage can lead to salinisation.

Sustainable agriculture depends on replenishing the soil while minimising the use of non-renewable resources, such as natural gas (used in converting atmospheric nitrogen into synthetic fertiliser), or mineral ores (e.g., phosphate). For irrigation systems to be sustainable they require proper management (to avoid salinisation) and must not use more water from its source than is naturally replenished. Useful measures include:1) modern irrigation systems such as drip irrigation with high water use efficiency; 2) improving water conservation and storage measures; 3) drought-tolerant crop species, 4) deficit irrigation; and 5) managing crops to reduce water loss. To conserve soil, useful soil management techniques include no-till farming, Keyline design, growing wind breaks to hold the soil, incorporating organic matter back into fields, stopping or minimising chemical fertilisers, protecting soil from water runoff erosion. The conventional monoculture (one crop) farming should be replaced by polyculture (a mixture of crops) to reduce disease or pest problems.

3.3.6 Population Control

In ancient times, people considered population as a source of political, economic, and military strength. However, it was gradually realised that the population should be controlled. In ancient Greece, Plato (427-347 BCE) and Aristotle (384-322 BCE) discussed the best population size for Greek city states and concluded that cities should be small enough for efficient administration and direct citizen participation in public affairs, but at the same time needed to be large enough to defend themselves against hostile neighbouring city states. In the 20th century, population control proponents have drawn from the insights of Thomas Malthus who argued that "Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetical ratio." Malthus advocated for the education of the lower class about the use of "moral restraint," or voluntary abstinence, which he believed would slow the growth rate. Paul Ehrlich, a US biologist and environmentalist, published 'The Population Bomb' in 1968, advocating stringent population control policies.

It is estimated based on the European standard of living that the Earth can only support a population of two billion individuals (Pimentel and colleagues, 2010). For other estimates with different living standards, carrying capacity of the Earth is between 4 billion and 16 billion (Wikipedia 'Over population'). Depending on which estimate is used, human overpopulation may or may not have already occurred. Nevertheless, the rapid recent increase in human population is causing some concern for the environment to cope with. Overpopulation will increase demand for resources such as fresh water and food, consume natural resources faster than the rate of regeneration (such as fossil fuels), and decrease living conditions.

The methods for population control include contraception, abstinence, reducing infant mortality (so that parents do not increase their family size to ensure at least some survive to adulthood), abortion, sterilisation, education and empowerment of women. The method(s) chosen can be strongly influenced by the religious and cultural beliefs of community members.

3.3.7 Sustainable City (eco-city)

Urbanisation can be planned and the engineering community should collaborate with other professions to design more eco friendly urban environment, such as eco-cities. A sustainable city (or eco-city) is a city designed with minimum environmental impact. A sustainable city should be able to feed itself with the food produced on the surrounding countryside, minimise the imported food from further afield, power itself with renewable sources of energy, create the smallest possible ecological footprint, produce the lowest quantity of pollution possible, use land efficiently, compost used materials, recycle waste or convert waste-to-energy. In contrast to rural or suburban areas, urban systems can be more environmentally sustainable because people and resource are located so close to one another to save transportation energy and use resources more efficiently.

The approaches for sustainable cities include: urban agricultural systems by either small scale farming plots or larger scale agriculture (e.g. farmscrapers), renewable energy sources (wind turbines, solar panels, or bio-gas created from sewage), various methods to reduce the need for air conditioning (planting trees and lightening surface colours, natural ventilation systems, increase in water features, and green spaces), improved public transport and increase in pedestrianisation to make driving more difficult to reduce car emissions, integration of business, industrial, and residential zones to shorten travel distances (people to live closer to the workspace), green roofs, zero-emission transport, zero-energy building, sustainable drainage systems (SuDS), energy conservation systems/devices, Xeriscaping (garden and landscape design for water conservation).

3.3.8 Sustainable Drainage System

Conventional drainage systems are designed to collect and convey storm water quickly which tend to cause downstream flooding and environmental pollution (e.g., combined sewage overflow). Sustainable drainage systems (SuDS) are designed to reduce the potential impact of new and existing developments with respect to surface water drainage discharges. They are intended to replicate natural systems with low environmental impact to drain away dirty and surface water run-off through collection, storage, and cleaning before allowing it to be released slowly back into the environment (e.g., water courses). SuDS should be easy to manage, require little or no energy input, resilient to use, environmentally and aesthetically attractive.

SuDS uses the following techniques: source control, permeable paving such as pervious concrete, storm water detention, storm water infiltration (e.g., reed beds, wetland), evapotranspiration (e.g. from a green roof), etc. Originally the term SUDS was used in the UK to refer to sustainable urban drainage systems. These developments may not necessarily be in "urban" areas, and nowadays the "urban" part of SUDS is usually dropped to reduce confusion. SuDS is called differently in many other countries (e.g., best management practice (BMP) and low-impact development in the United States, and water-sensitive urban design in Australia).

Further reading materials

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4 Remote Sensing of Environment

4.1 Introduction

Remote sensing is the acquisition of information at a distance about physical objects on the Earth in order to detect and classify objects by means of reflected or emitted electromagnetic energy. There are two types: 1) passive remote sensing and 2) active remote sensing. A passive sensor detects radiation that is emitted from the target object or reflected by the object from a natural radiation source (e.g., sun). An active device emits energy to the target object and uses a sensor to detect and measure the reflected or backscattered energy (e.g., radar and lidar). The time delay between emission and return can be used to measure the location and speed of an object.

4.2 Electromagnetic Radiation

All objects emit and reflect electromagnetic radiations (except the idealised cases such as no emission for absolute zero and no reflection for black body). Remote sensing uses sensors to record electromagnetic radiation emitted or reflected from the target object which goes through the atmosphere. Electromagnetic radiation is expressed by three properties: *wavelength* (in length, such as mm), *frequency* (in hertz) and *amplitude* (spectral irradiance in watts per square meter per micrometer). The relationship between frequency and wavelength is expressed as

$$c = \lambda v \tag{4.1}$$

where c is the speed of electromagnetic radiation at 2999,893 km/s, λ is the wavelength and v is frequency. Their common units are listed in Table 4.1.

Table 4.1 Units of Length and Frequency

Length		Frequency	
km	10^3 m	Hz	1
m	1 m	kHz	10^3
cm	10^{-2} m	MHz	10^6
mm	10^{-3} m	GHz	10^9
µm	10^{-6} m		
nm	10^{-9} m		

The major categories of electromagnetic spectrum are listed in Table 4.2 and represented in Figure 4.1.

Table 4.2 Categories of the Electromagnetic Spectrum

Category	Range
Gamma Rays	<0.03nm
X-rays	0.03 - 300nm
UV	0.30 - 0.38µm (300-380nm)
Visible light	0.38 - 0.72µm (380 - 720 nm)
Blue	0.38 - 0.5µm
Green	0.5 - 0.6µm
Red	0.6 - 0.72µm
Infrared	
Near	0.72 - 1.3µm
Mid	1.30 - 3.00µm
Far	7 - 1000µm (1mm)
Radio waves	1mm - 100km
Microwave	1mm-30cm

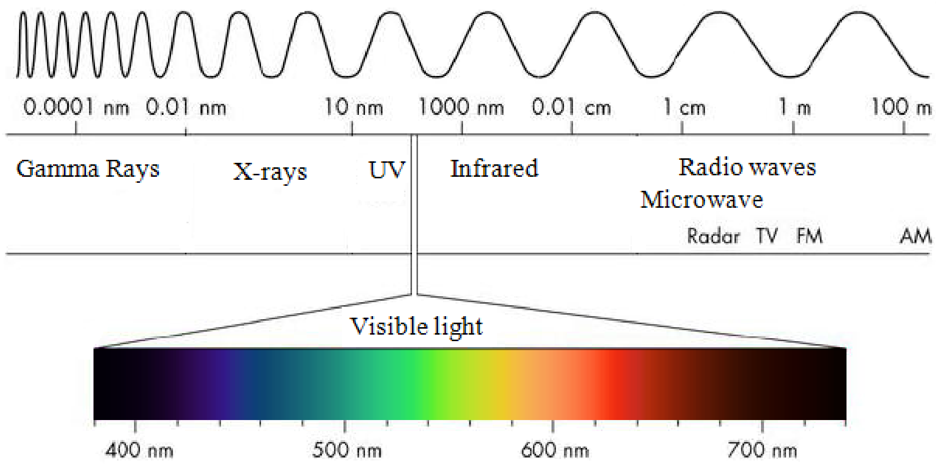

Figure 4.1 Electromagnetic Spectrum

The total radiation power is measured by *radiant flux* in W. The *irradiance* measures radiant flux per unit area landing on a surface (W/m^2) and radiant emittance is radiant flux per unit area emitted from a surface (W/m^2). If each frequency is considered separately, 'spectral' is added in front of them such as *spectral irradiance* ($W/m^2/nm$).

The radiation from an object depends on its temperature and *emissivity* (written in ε) . *Emissivity* represents the relative ability of a material surface to emit radiation related to a *black body* at the same temperature, which varies on factors such as temperature, emission angle and wavelength. A black body is an idealised physical body that absorbs all incident radiation with no reflection, hence its emissivity is 1. A perfect reflector's emissivity (a white body) is 0. In the nature, all objects are *gray bodies* whose emissivities lie between 0 and 1.

There are three important laws in radiation:

1. *Kirchhoff's law:* at thermal equilibrium, the emissivity of a body (or surface) equals to its absorptivity. It could be described as 'a poor reflector is a good emitter, and a good reflector is a poor emitter';
2. *Stefan-Boltzmann law*: the total emitted radiation is linked with the temperature (absolute temperature) $W = \sigma T^4$ (W/cm^2), where $\sigma = 5.6697 \times 10^{-8}$. This law may be used to estimate the temperature of a remote body;
3. *Wien's displacement law:* the wavelength at which a black body's maximum emitted radiation is related to its temperature as $\lambda = 2897.8 / T$. As a black body becomes hotter, the wavelength of its maximum emitted radiation shifts to a shorter wavelength, and vice versa. A black body appears black at the Earth ambient temperatures because it mainly emits longer wavelength infrared radiation and does not emit any detectable visible light.

4.3 Interactions with the Atmosphere and Earth Surface

4.3.1 With the Atmosphere

The electromagnetic radiation interacts with the atmosphere in three ways:

1. *scattering:* redirection of electromagnetic radiation by particles or large molecules in the atmosphere. *Rayleigh scattering* occurs when atmospheric particles (mainly large molecules of nitrogen and oxygen gases) are very small relative to the radiation wavelength and it is in proportion to the inverse of the fourth power of the wavelength. Blue light is scattered 4 times as much as red light which explains the blue sky during clear day and reddish colour at sunset. Due to Rayleigh scattering, radiation in the blue and ultraviolet spectrum is significantly scattered and is usually not used in remote sensing. On the other hand, *Mie scattering* is caused by large atmospheric particles (dust, pollen, smoke, tiny water droplet) that are equivalent in size to the radiation wavelength. Mie scattering is also wavelength dependent, but the relationship is more complicated. If particles are much larger than the radiation wavelength (e.g., water droplets or large dust particle), *non-selective scattering* will occur which is not wavelength-dependent. All visible wavelengths are scattered equally so that they are observed as a whitish or greyish haze.

2. *absorption:* gradual loss of radiation intensity through a medium (also called attenuation). The radiation energy is taken up by the medium and transformed to other forms such as heat. The Earth atmosphere is an important barrier to radiation transmission by attenuation. The attenuation spectrum is referred to as atmospheric window (Figure 4.2). The wavelength severely attenuated by the atmosphere is usually not effective for remote sensing.

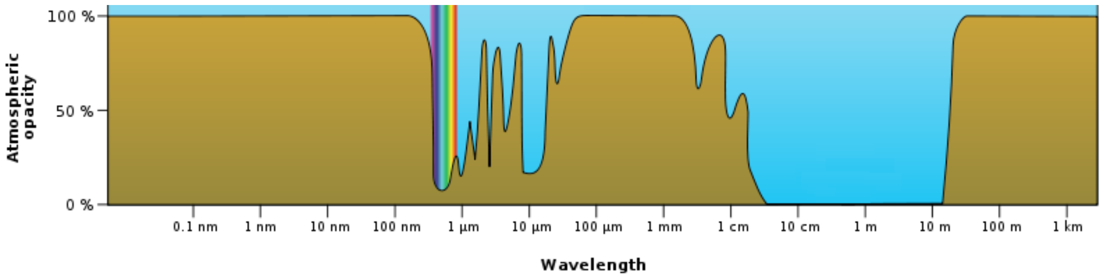

Figure 4.2 Earth's atmospheric window (Adopted from Wikipedia 'Absorption', 2012)

3. *refraction:* change of radiation direction at the contact area between two different media. It happens in the atmosphere as radiation passes through atmospheric layers of varied humidity, temperature, and density. The bending of microwave radar beam is the main reason for Anaprop (Anomalous propagation).

4.3.2 With the Surface

The electromagnetic radiation interacts with the Earth surface in three ways:

1. *reflection:* the change of radiation direction at the Earth surface. It depends on surface irregularities (i.e., roughness) in relationship to the radiation wavelength. If a surface is smooth relative to wavelength, *specular reflection* occurs and almost all incident radiation is reflected in a single direction (i.e., mirror-like). Specular reflection usually occurs with mirror, smooth metal, calm water, etc. If a surface is rough relative to wavelength, *diffuse reflection* occurs and incident radiation is reflected in many directions (scattered). Diffuse reflection usually occurs with non-shiny surfaces such as ground, wall, paper, etc. An ideal diffuse reflector is known as a Lambertian surface which reflects incident radiation equally in all directions. A Lambertian surface is usually used as an approximation to the target object in remote sensing. However, many actual surfaces have complex reflection patterns influenced by surface geometry (e.g., shape, size, orientation, etc).
2. *transmission:* the passing of radiation through a material such as vegetation leaves. It varies greatly with wavelength (e.g., vegetation leaves are generally opaque to visible light, but transmit significant amounts of radiation in infrared and microwave bands). Transmission is opposite to absorption.
3. *absorption:* loss of radiation energy in the Earth surface which is transformed into other energy forms such as heat.

4.3.3 Spectral Signature

Different objects on the Earth surface may have different emitted/reflected radiation features in a range of wavelengths, which are called spectral signatures (Figure 4.3 A). With cameras and other remote sensing instruments, it is possible to observe the brightness of an object across several spectral bands (Figure 4.3B). The spectral signature would help the identification of different land covers/land surfaces (vegetated and non-vegetated areas, diseased or stressed vegetation, certain types of plants and soil characteristics, urban areas, and water body). It should be noted that spectral signatures change both over time (e.g., different growth seasons) and space (e.g., different proportions of tree species in a forest), so it is important to use the normalised index in object classifications. From Figure 4.3, it is clear that vegetation gives very strong reflection to infrared channel over red channel. This characteristic can be used to identify vegetation cover over the globe based on NDVI (the Normalised Difference Vegetation Index). NDVI is usually calculated as follows,

$$NDVI = \frac{\text{near infrared - red}}{\text{near infrared + red}} \tag{4.2}$$

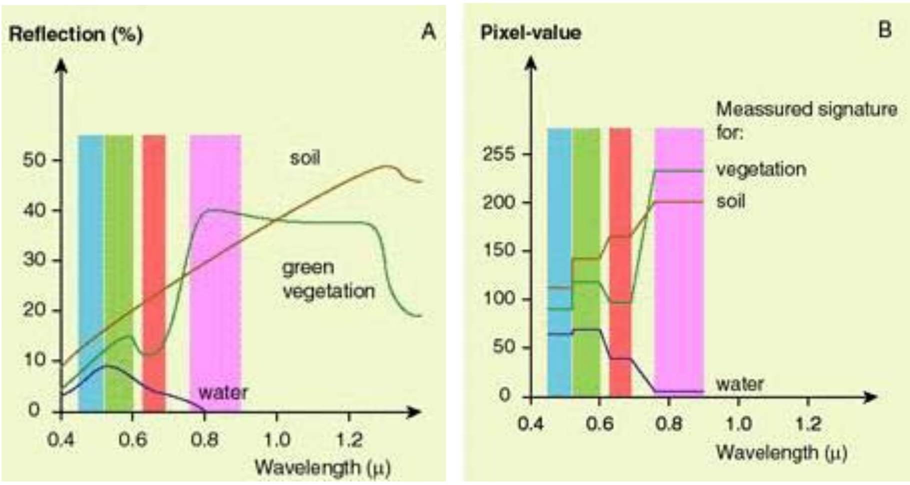

Figure 4.3 A) Spectral signatures of soil, vegetation and water: B) quantified values across different bands (Adopted from ESA, 2012)

The spectral information collected by remote sensing is broadly in two categories: multispectral and hyperspectral images (Figure 4.4). Multispectral images are captured at discrete bands with gaps between them. Hyperspectral images have narrow spectral bands over a continuous spectral range, which are memory demanding and less widely used in comparison with multispectral images.

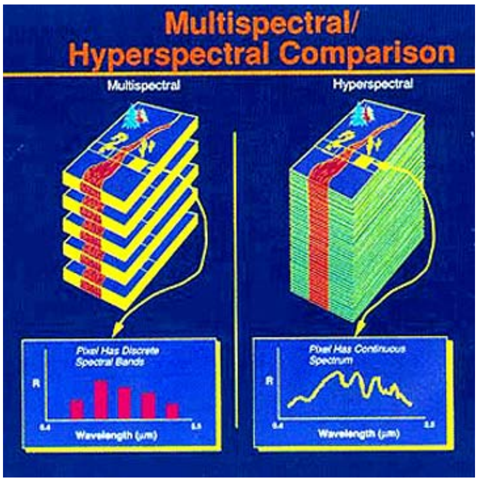

Figure 4.4 Hyperspectral and Multispectral images (Wikipedia, 2012)

4.4 Sensors

Remote sensing takes three forms: 1) reflection of solar radiation from the Earth. The spectrum mainly includes the visible light and near infrared; 2) radiation emitted from the Earth. Since the Earth has a much lower temperature than the Sun, the radiation from the Earth is mainly at longer wavelength; 3) reflection of the emitted radiation from the sensor (the sensor illuminates the object with its own radiation instead of the Sun). Various sensors are available to capture the information of those forms.

4.4.1 Aerial Camera

Aerial photography is a basic form of capturing remote sensed images using an aerial camera in visible light and near infrared spectrum. Aerial cameras have the following components: 1) a lens to focus light on the film; 2) a film to record images and 3) a shutter to control exposure. There are three types of cameras used in aerial photography: 1) *metric cameras* (i.e., cartographic cameras) are used to capture high quality images with a minimum optical and geometric error; 2) *strip cameras* capture images by moving film past a fixed slit. The speed of film movement is synchronised with the speed and altitude of the aircraft to provide suitable exposure; 3) *panoramic cameras* use a lens with a narrow field of view to scan across a wide strip of land. Panoramic photographs have serious geometric distortions because of the forward motion of the aircraft during the side-to-side scan of the lens.

4.4.2 Radiometer

It is used to collect reflected or emitted radiation in a wide range of frequencies. The most common are visible and infrared sensors, followed by microwave. Examples include the Moderate-resolution Imaging Spectroradiometer (MODIS), the Advanced Very High Resolution Radiometer (AVHRR) and the Enhanced Thematic Mapper Plus (ETM+). Radiometers may collect images in panchromatic, multispectral, hyperspectral and full spectral modes. Panchromatic images record the total radiation across a wide range of spectrum (e.g., visible light). Multispectral images are captured at several specific wavelengths (i.e., bands). Hyperspectral deals with imaging narrow spectral bands over a continuous spectral range so that an entire spectrum is acquired. Full Spectral Imaging (FSI) acquires data as spectral curves (not at different wave bands). FSI information is contained in the shape of the spectral curves. As a result, a significant reduction in data rate and volume could be achieved in comparison with hyperspectral images.

4.4.3 Microwave Radiometer

A microwave radiometer measures energy emitted at sub-millimetre-to-centimetre wavelengths (at frequencies of 1-1000 GHz). Examples of microwave radiometers include the Special Sensor Microwave/Imager (SSM/I), Scanning Multichannel Microwave Radiometer (SMMR), the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) and the Microwave Imaging Radiometer with Aperture Synthesis (MIRAS).

4.4.4 Radar Altimeter

A radar altimeter measures the altitude using the time for a microwave pulse to reflect from the Earth surface to the instrument. Coupled with GPS, a radar altimeter can be used to determine the terrain.

4.4.5 Synthetic-Aperture Radar (SAR)

A SAR uses a single physical antenna gathering signals at different positions at different times. The phase shifts from those signals enables the radar to achieve finer spatial resolutions than the conventional beam scanning radars. For the Interferometric synthetic aperture radar (InSAR or IfSAR), two or more SAR images taken at different times can be used to generate maps of surface deformation based on the differences in the phase between them. It can potentially measure centimetre-scale changes in deformation over time spans of days to years.

4.4.6 LIDAR

LIDAR (Light Detection And Ranging) is an instrument for measuring the distance to or other properties of a target. A pulsed laser beam in ultraviolet, visible or near infrared bands is used to illuminate the target. The LADAR components include laser, scanner, photodetector and position systems.

4.5 Remote Sensing Platforms

There are various platforms to mount remote sensors, such as balloons, kites, rockets, helicopters, aircrafts, satellites, etc. Only satellites are covered here since they are the most commonly used means for data acquisition. A satellite moves along its orbit around the Earth. A normal orbit forms an ellipse with one focus at the Earth centre with key parameters: apogee ***A*** (the point farthest from the Earth), perigee ***P*** (the point closest to the Earth), ascending node ***AN*** (the point where the satellite crosses the equator from south to north), descending node ***DN*** (as *AN* except the opposite direction), inclination ***i*** (the angle between satellite moving direction at *DN* with respect to the equator). An inclination of zero degrees means the satellite orbits the Earth in its equatorial plane, in the same direction as the Earth rotates. The orbit altitude controls the time required for a satellite to circle the Earth (it increases with altitude).

There are three main orbit options based on inclination: geostationary, polar and inclined. With an inclination of zero degrees and altitude of 35,790 km, a satellite has the same rotational period (i.e., 23 hrs 56 mins, 4.09 secs) as the Earth and remains stationary above the Earth surface (i.e., geostationary). Geostationary satellites are suitable for communications and weather monitoring due to its continuous availability in time, but it has a poor spatial resolution in the polar regions. The polar orbit has an inclination of 90 degrees, which means the satellite passes the poles on each orbital revolution and covers the whole globe. An inclined orbit falls between/beyond 0 degrees (geostationary orbit) and 90 degrees (polar orbit). Such an orbit may be more suitable for a specific region. A special case of the inclined orbit is sun-synchronous which is useful in reducing variation in illuminations caused by differences in time of day so that a satellite passes over the same Earth point at the same solar time at altitudes of 600 to 800 km (with a period around 100 minutes). It has an inclination of 98 degrees (close to a polar orbit).

4.6 Data Processing

Remote sensing usually measures the interested features of the target object indirectly (e.g., precipitation). A data based mathematical model (e.g., regression model, Artificial Neural Network, Support Vector Machines) is needed to derive the features to be measured (an inverse problem).

Some key properties of the remote sensing data include: 1) *spatial resolution*: the size of a pixel (e.g., Landsat 7's spatial resolution ranges from 15 to 60m); 2) *temporal resolution:* the repeated coverage of the scanned images (e.g., Landsat 7 has a temporal resolution of 16 days). This is useful for detecting temporal changes of the scanned object; 3) *spectral resolution*: the wavelength width of the different frequency bands (e.g., Landsat 7's spectral resolutions are from 0.07 to 2.1 mm to cover seven bands including visible and infra-red spectrums); 4) *radiometric resolution:* the number of distinguishable different radiation intensities (e.g., 8 bits are equal to 256 levels). Normally, the instrument noise would limit the achievable resolution.

The data processing includes the follow actions:

1. *Georeference*: to correct the distorted images by matching with the known points on the ground (typically 30 or more points per image aided by computer software) to warp the image so that the distortion is minimised. In recent years (since 1990s), most satellite images are fully georeferenced by data providers;

2. *Radiometric conversion:* to convert the digitised pixel values (e.g., raw digital number in 8 bits) to actual analogue values (e.g., radiance);
3. *Atmospheric correction*: to correct the effect of the atmosphere based on the wavelength, sensor height and the purpose (NCAVEO, 2011). Although the uncorrected raw digital number is acceptable for a one-off image classification, it is more useful to convert the raw digital number to 'at sensor' radiance and derive ground leaving radiance from the 'at sensor' (or 'top-of-atmosphere') radiance so that the results may be more reliable and compared with different sensors. The atmospheric conditions can be based on the generic prevailing weather conditions coincided with the scanned image or from the downscaled reanalysis weather data using WRF or MM5.

Data processing levels include (based on NASA and WMO):
Level 0: raw instrument data (usually not available to users);
Level 1: time referenced Level 0 data with the Earth-location and instrument calibration information;
Level 2: derived geophysical values (e.g., temperature, soil moisture) at instrumental pixel resolution;
Level 3: geophysical values on uniform space-time grids (interpolated from Level 2), which are easy to handle by GIS software;
Level 4: output from the analysis models.

Some commonly used image processing systems include
ENVI (ITT Corporation, http://www.ittvis.com/language/en-US/ProductsServices/ENVI.aspx)
GRASS GIS (GRASS Development Team, a free software system, http://grass.osgeo.org/)
IDRISI (Clark Labs at Clark University, http://www.clarklabs.org/)

4.7 Field Observation

Field observations are carried out at or near ground level acting as 'ground truth' in support of remote sensing analysis. They are used for 1) to verify the remote sensing results; 2) to provide training data for image classification; and 3) to provide the spectral properties of the object (e.g., different plants, soils, water bodies). The field observation should contain three key elements: attribute (vegetation type, soil moisture, etc.), location and time.

Nominal data are qualitative designations of delineated regions, such as forest, water, grassland, etc. In the field, nominal data can be collected at points or for small areas. To cover a large area, it is convenient to bring maps or aerial photographs to annotate the nominal labels. Documentations usually include notes, sketches, ground/sky photographs, videos, etc.

Biophysical data represent physical features of vegetation cover (e.g., type, size, form, spacing, leaf area index- LAI) and soil (e.g., texture, mineralogy, soil moisture). They tend to vary with time so it is important that their measurements should be linked with remote sensing images. Their record should also include time, location and weather. Biophysical data are collected at point and should be extrapolated to large areas by a suitable algorithm (e.g., simple average, Kriging). They complement nominal data with more precise meaning of the individual nominal labels.

Radiometric data are collected by field spectroradiometers to measure brightness near the ground surface which can be used to analyse the corresponding brightness recorded by the remote sensing device. A spectroradiometer is designed to measure the spectral power distribution of illuminants and equipped with a handhold probe connected to the measuring unit by a fibre optic cable. The device is able to separate radiation into different spectral regions by filters or diffraction gratings. A hand-held 2or 3 band spectroradiometer has a typical spectral bandwidth of 300nm to 1000nm (cover the channels of green, red, and near-IR). Brightness can be presented as radiance (absolute brightness to represent the radiation seen from the target) or reflectance (relative brightness as a ratio of the radiation from the target and the radiation to the target, e.g., albedo). Reflectances are convenient in comparing with other data because they are less influenced by the variations in illumination and field practice. A reference panel is needed to provide a uniform reflective brightness as a reference target. It is made from a pure white surface with well known reflectance properties (such as barium sulphate and Spectralon). Some instruments have the ability to match the spectral ranges and resolutions to specific satellite sensors such as SPOT TM.

The field of view to the features to be observed has an important influence on data quality. A foreoptic (a removable attachment) should be fitted to the probe to restrict its view from 1 to 10 degrees. The indirect radiation from the operator's clothing and irrelevant objects should be avoided. The probe may be immersed in liquids (e.g., to measure radiation from water bodies), around the ground surface by hand-holding or situated on truck-mounted booms with overhead views to better represent the viewing perspective of remote sensing devices in the sky.

4.8 Applications

Remote sensing has a wide range of applications such as vegetation cover, erosion, pollution, forestry, weather, and land use which can be imaged, mapped and tracked.

4.8.1 Vegetation

Vegetation plays an important role in the environment. There are several types of vegetation classifications such as floristic (botanical), physiognomy and structure (life form), ecological (function in ecosystems), etc. For environmental applications, ecological, physiognomy and structure classifications are more relevant. Timing of vegetation remote sensing may be very important. In a forested area, mapping of the understory should be carried out in early spring when the forest canopy is not fully developed to cover the small plants underneath.

Chlorophyll in plants absorbs sunlight in photosynthesis with preference in blue and red spectrums as shown in Figure 4.5 (as much as 70-90%). As a result, green and near-infrared (NIR) lights are reflected (especially NIR) and vegetations appear as green to human eyes (as shown in Figure 4.3). Different vegetations are more apparent in NIR than in visible light spectrum (e.g., with increasing NIR reflectances in coniferous forest, broadleaf and grass), so NIR could be used to distinguish vegetation types. For the same vegetation, NIR reflects its vegetative vigour (i.e., stronger vegetation with more reflective NIR). At mid infrared spectrum, vegetation water content plays an important role and could be used to check the water content in vegetation (e.g., drought condition, maturity of plant) as shown in Figure 4.6.

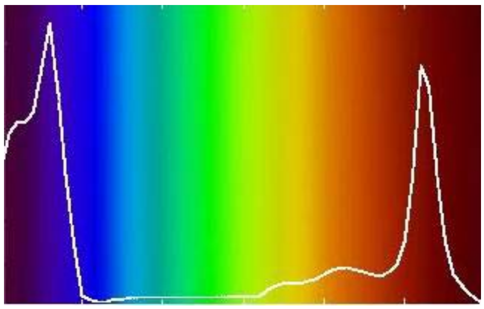

Figure 4.5 Absorption spectrum of a typical plant

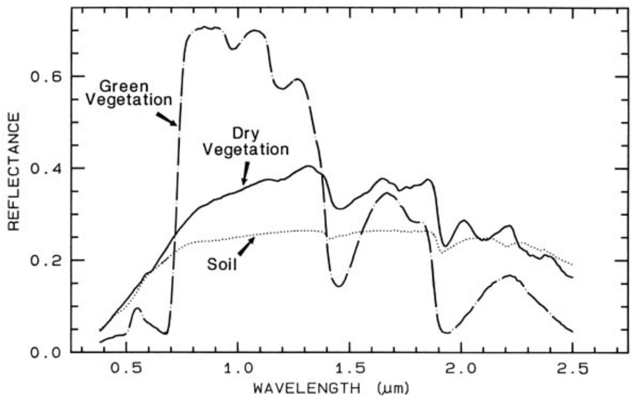

Figure 4.6 Reflectance of dry and green vegetation (Blue Marble Project, 2003)

Vegetation index can be derived based on the vegetation reflectance (e.g., NDVI). The green spectrum may be used instead of NIR albeit it is less effective. It should be noted that vegetation index is influenced by viewing angle, leaf orientation, soil background, atmosphere (some bands are affected more than others), etc., which may cause difficulties in analysing vegetation changes with time. It may help to convert sensor digital values to radiance before vegetation index is calculated. Vegetation index may be used to monitor leaf area index, to map vegetated areas from non-vegetated areas, to distinguish vegetation types and densities and to check vegetation change with time.

It is possible to investigate foliar chemistry using hyperspectral images such as foliar nitrogen content (e.g., in bands 1265-1555 nm). Lidar data are able to provide information on vegetation height, a useful feature for forest management.

4.8.2 Landform

Land form remote sensing covers geology, topography, etc. Aerial photos are useful in identifying geological structure and terrain. Various drainage patterns can be derived from remote sensed images. It is possible to spot linear features such as fault lines (Figure 4.7).

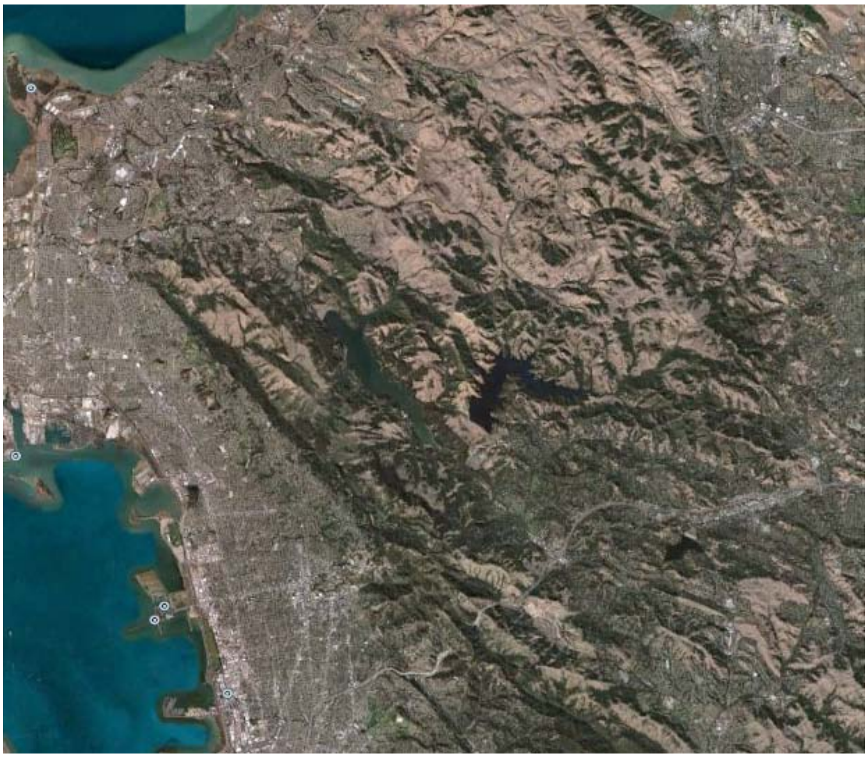

Figure 4.7 Landform image of San Francisco Bay (Google Earth, 2012)

In the area with vegetation coverage, geobotany may be used to derive the underneath geochemical information. Geological materials influence the supply of nutrients (e.g., micronutrients such as barium, magnesium and calcium) or toxic elements (e.g., heavy metals), which may be reflected in vegetation growth. Spectral emittance and reflectance of rocks and minerals are closely related to their physical and chemical properties.

4.8.3 Water

The deep pure water appears blue to blue-green. The sediment concentration influences the spectral properties of a water body change by increasing its overall brightness in the visible spectrum and shifting its peak reflectance from blue to green with a broader shape (Figure 4.8).

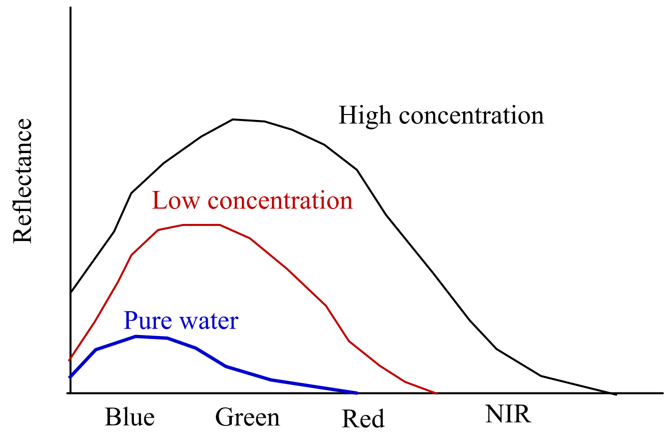

Figure 4.8 Spectral change with sediment concentration

The roughness of water surface is linked with the reflectance. Wave-roughed surfaces are brighter than smoother ones (similar to reflectors in bicycles). With an active radar system on a satellite, the sea wave height and velocity can be derived from the received signal based on the radar wavelength and bean geometry.

If water is clear and the water body bed reflectance is uniform, it is possible to derive the depth of water using multispectral images. This is because different bands of visible lights have different reflectance from various depths of water (up to 20m).

Evapotranspiration over land may be estimated from satellite sensed vegetation, land temperature and total radiation (e.g., using the Penman Monteith formula). Passive and active microwave sensors are able to provide soil moisture information.

Sea surface temperature (SST) represents the average temperature of the ocean surface within the upper meter. Remote sensing is only able to detect the surface temperature within the upper 1mm, which is still useful since there is a good correlation between STT and remote sensed temperature. The wavelength used is around the peak of the blackbody radiation from the Earth (10 μm).

Since phytoplankton (microscopic plants in water) contains chlorophyll (as land vegetation), multispectral remote sensors are able to detect its concentration in water. Other materials such as bacteria, fungi, algae, silts and clays may also be detected.

4.8.4 Land Use and Land Cover (LULC)

Land use refers to use of the land surface by humans in an economic sense (agricultural, industrial, commercial, residential) and land cover shows the physical Earth surface features (lake, forest, urban). In practice, land use and land cover are considered together. In 1970s, USGS specified Level I (urban, agricultural, rangeland, forest, water, wetland, barren, tundra, perennial snow or ice) and Level II categories (with more details). Data analysts may add further detailed Level III (or more) for particular applications.

LULC identification is based on image interpretation. Crop land usually has regular shapes. Forests may have rough textures and medium dark tones with irregular edges. Transportation is featured with linear patterns. Usually predominant category is used to identify each LULC parcel.

To map the changes of LULC, maps taken at two different dates should have the same classification system, scale, geometry and details.

4.8.5 Rainfall

Rainfall may be estimated by visible, infrared or microwave bands. Infrared and visible light instruments are capable of studying the cloud upper layer only and thus they can provide indirect information of rain. In contrast, passive microwave sensor can observe rain drop distributions above the Earth surface. Satellite rainfall is valuable in ungauged catchments. In Infrared and visible bands, GOES (USA), METEOSAT (Europe, Africa, and western Asia) and MTSAT (eastern Asia) have been used to provide rainfall data at continental scales. In passive microwave, the Global Precipitation Measurement (GPM) mission (scheduled to fly in the year of 2013) and its predecessor Tropical Rainfall Measuring Mission (TRMM) are able to measure the Earth's precipitation structure.

Further reading materials

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5 Environmental Risk

Environmental risk due to various environmental hazards is an important topic for environmental engineers to recognise and understand in order to protect human society and ecosystems from harms or damages at local, regional or global scales. For example, to deal with contaminated soil and ground water at a brown field, risk and exposure assessment help engineers choose an optimal solution to either treat the hazard (e.g., to remove the contaminants from the soil and water) or reduce the exposure (e.g., to cover up the land with a barrier).

5.1 Hazards

A hazard is a threat to life, health, property, or ecosystems, i.e., it involves something that could potentially be harmful. Therefore, when a dormant hazard comes to fruition, it will cause physical damage or destruction, loss of life, or drastic change to the environment, and result in an incident, accident, emergency event, or disaster. Hazards may be broadly classified into two groups:

Man-made hazards (also called anthropogenic hazards): created by humans due to human intent, negligence, or error, such as crime, terrorism, war (sociological hazards), industrial hazards, power outage, hazardous materials (technological hazards), etc.

Natural hazards: caused by a natural process with a negative effect on people or the environment, such as volcanoes, floods, earthquakes, etc. Many natural and man-made hazards are interrelated (e.g. earthquakes may cause tsunamis which in turn damage nuclear power plants to release radioactive waste).

5.2 Environmental Hazards

Environmental hazards include hazardous material pollution and natural hazards.

5.2.1 Hazardous Wastes

Hazardous wastes are classified into several categories such as explosive, flammable, irritant, carcinogenic, corrosive, etc. Nowadays, landfill of hazardous wastes is banned in the EU and incineration should be used to dispose them. Assessment of waste sources is quite a difficult task as waste producers do not always retain inventories of their waste streams because hazardous waste is a liability and a cost burden. Therefore, waste assessment is a highly expensive exercise requiring time, patient, training and money. Among various effects of hazardous wastes, toxicity is of direct concern by the public. Environmental toxicology is an interdisciplinary science field dealing with the effects of chemicals on living organisms.

Toxic effects are divided into two types: carcinogenic and noncarcinogenic. A carcinogen promotes or induces tumours with uncontrolled abnormal growth and division of cells. Noncarcinogenic matters cause toxicological responses without carcinogenic effects, such as organ damage, neurological damage, learning difficulties, etc. A common method of expressing toxicity is the median lethal dose (LD_{50}), which is the dose causing the death of 50 percent of a test organism population. The median lethal dose is represented as the mass of chemical dose per body mass of the test organism using the unit of mg/kg. Stating it this way allows the relative toxicity of different substances to be compared and normalised for the variation in the size of the animals exposed (although toxicity does not always scale simply with body mass). It should be noted that LD_{50} measures acute toxicity only (as opposed to chronic toxicity at lower doses). The species-specific nature of toxicity presents a shortcoming in extrapolating animal test results to humans. When animal studies are used to determine standards for human exposure, a philosophy of 'safe than sorry' is adopted to apply a significant safety factor to set a conservative level by several orders of magnitude (the safety factor is usually between 10 to 1000).

5.2.2 Natural Hazards

Natural hazards can be further divided into geological hazards and hydrometeorological hazards.

Geological hazard examples include

1. ***earthquake***: a result of sudden release of energy in the Earth's crust that creates seismic waves. Earthquakes are caused mostly by ruptures of geological faults, but also by other events such as volcanic activities, landslides, mine blasts, and nuclear tests. At the Earth's surface, earthquakes manifest themselves by shaking and sometimes displacement of the ground. When the epicenter of a large earthquake is located offshore, the seabed may be displaced sufficiently to cause a tsunami. Major earthquakes can cause losses of human lives and huge damages to buildings as illustrated by Figure 5.1;

Figure 5.1 Damaged building by the Great Sichuan Earthquake, China, 2008

2. ***landslide***: an event when the stability of a slope changes from a stable condition to an unstable condition due to natural causes (groundwater, erosion, earthquake, volcanic eruptions) or human activities (deforestation, blasting, earthwork). Landslides include debris flows (Figure 5.2), earth flow, shallow landslide, deep-seated landslide, etc.

Figure 5.2 Landside damage in Sichuan, China, 2010

3. ***avalanche***: a sudden, drastic flow of snow down a slope, occurring when either natural triggers (such as loading from new snow or rain) or artificial triggers (such as snowmobilers, explosives or backcountry skiers) overload the snowpack. Avalanches are most common during winter or spring, which can cause loss of life and destroy settlements, roads, railways and forests. The size of an avalanche, its mass and its destructive potential are rated on a logarithmic scale, typically of 5 categories;
4. ***volcanic eruption***: the release of power from a volcano. The eruptions come in many forms ranging from daily small eruptions, to megacolossal eruptions, or supervolcanoes. Volcanic eruptions arise through three main mechanisms: a) gas release under decompression causing magmatic eruptions, b) thermal contraction from chilling on contact with water causing phreatomagmatic eruptions, and c) ejection of entrained particles during steam eruptions causing phreatic eruptions.

Hydrometeorological hazards examples include

1. ***flood*****:** an overflow of water that submerges the land that is normally dry. There are various types of floods such as urban flood, fluvial flood, pluvial floods, flash floods, coastal flood and groundwater flood, etc. Floods tend to cause damages to buildings and threaten human lives;
2. ***drought*****:** an extended period of months or years with consistently below average precipitation resulting in a deficiency in a region's water supply. A severe drought can have significant environmental, agricultural, health, economic and social consequences;

3. ***hurricane*:** it is also called cyclonic storm, tropical cyclone, and typhoon. Hurricanes forms over the oceans caused by evaporated water from the ocean and becomes a storm. The Coriolis Effect causes the storms to spin, and a hurricane is declared when this spinning mass of storms attains a wind speed greater than 74 mph (119 km/h). While tropical cyclones can produce extremely powerful winds and torrential rain, they are also able to produce high waves and damaging storm surge as well as spawning tornadoes;
4. **heat wave:** a prolonged period of excessively hot weather, which may be accompanied by high humidity. Severe heat waves have caused catastrophic crop failures, thousands of deaths from hyperthermia, and widespread power outages due to increased use of air conditioning.

5.3 Environmental Risks

'Hazard' and 'Risk' are different terms. In environmental engineering, risk is defined as the expected outcome of an environmental hazard (human injury, disease, death, economic losses or ecosystem damages). Generally, the risk is a function of hazard and its exposure

$$\text{Risk}=f\,(\text{Hazard, Exposure}) \tag{5.1}$$

The meaning and unit of the formula vary depending on the specific hazards. Risk can be reduced by lowering either hazard or exposure, or both.

The risk to the health of human due to harmful carcinogenic chemicals is expressed as.

$$\text{Risk}=\text{Risk per unit dose } \times \text{Exposed dose} \tag{5.2}$$

where risk is the **probability** of a person suffers from the adverse effect of the hazards (e.g., to develop cancer due to exposure to carcinogens), risk per unit dose is the harm caused by a unit exposure of a hazardous material (i.e., how strong the chemical is harmful), exposed dose is the contact of a human and the chemical (expressed as dosage and duration). In humans, there are three major exposure pathways: ingestion (eating/drinking), inhalation (breathing) and dermal (skin) contact. The default exposure duration is 70 years and if a person's exposure is shorter than 70 year, the risk calculated should be scaled by the ratio of the actual duration to 70 year. For carcinogens, there is no threshold for chemicals to take effects (i.e., linear dose-response relationship). If the risk is higher than the specified probability, it is considered not acceptable (e.g., greater than 10^{-6}).

For noncarcinogens, a threshold is needed for them to have effects and a dose below the limit is assumed safe. This threshold is called reference dose. The risk is expressed as a ratio between the exposed dose to reference dose.

$$\text{Risk (called Hazard quotient)}=\frac{\text{Exposed dose}}{\text{Reference dose}} \tag{5.3}$$

The risk is considered as safe if it is equal or less than 1.

For the risk linked with natural hazards (e.g., floods), it is defined as

$$\text{Risk} = \text{Probability} \times \text{Expected adverse consequences} \tag{5.4}$$

where risk is the **expected losses** from the hazard event (note, it is not a probability anymore), probability is the likelihood of the hazard event, expected adverse consequences are the result of the event (in economic loss or deaths). For example, a 50% chance of flood causing £1000 worth of damage has the same risk as a 0.1% chance of flood causing losses of £0.5M (both have the expected risk values of £500).

In reality, natural hazards tend to occur with a range of magnitudes at varied probabilities (e.g., a larger flood occurs less frequently than a smaller flood). The total risk for a hazard should be the sum (or the definite integral for continuous variables) of the risks from different magnitudes with their corresponding probabilities.

$$\text{Risk} = \sum_{\text{hazard across its magnitudes}} \text{Probability} \times \text{Expected adverse consequences} \tag{5.5a}$$

or

$$\text{Risk} = \int_0^1 \text{Probability density function} \times \text{Expected adverse consequence function} \times dp \tag{5.5b}$$

This formula can also be used to integrate risks from different independent hazards. For dependent hazards, more detailed probability on joint and union occurrences should be considered.

5.4 Risk Perception

Risk perception is a subjective judgment that people make about the characteristics and severity of a risk. It has been found that people use a number of heuristics to evaluate information which usually leads to inaccurate judgments in some situations (cognitive biases). There are several factors that influence human's risk perception. One important factor is the familiarity to a hazard (if people are often exposed to a hazard and know a lot more on it, there is a tendency to underestimate the risk). A second factor is whether or not the risk is voluntary. When a person voluntarily takes on a risk, he or she also usually underestimates the risk (e.g., smoking, driving a fast car). People tend to feel it is more acceptable to choose a risk than to be put at risk by other people (e.g., contamination from factories). A third factor is people are more concerned with current risks (with immediate effect on everyday life) than long term risks (e.g., climate change, population growth). Another factor is that risk events interact with individual psychological, social and other cultural factors in ways that either increase or decrease public perceptions of risk. These ripple effects caused by the amplification of risk include enduring mental perceptions, impacts on business sales, and change in residential property values, changes in training and education, or social disorder.

5.5 Risk Assessment

Risk assessment is an important component in risk management. Risk assessment is the determination of risk related to a hazard. Methods for assessment of risk may differ between sectors and whether it pertains to environmental or public health risk assessment.

In the context of public health, risk assessment is the process of quantifying the probability of a harmful effect to individuals or populations from hazard or exposed dosage above a specific threshold. It involves 1) hazard identification: to determine the qualitative nature of the potential adverse consequences of the contaminant and the strength of the evidence it can have that effect. This is done by drawing from the results of the sciences of toxicology and epidemiology; 2) Dose-Response Analysis: to determine the relationship between dose and the probability or the incidence of effect (dose-response assessment). This is based on extrapolating results from experimental animals to humans. In addition, the differences between individuals due to genetics or other factors mean that the hazard may be higher for particular groups, called susceptible populations; 3) exposure quantification: to determine the amount of a contaminant (dose) that individuals and populations will receive. This is done by examining the exposure. As different locations, lifestyles and other factors likely influence the amount of contaminant received, particular care is taken to determine the exposure of the susceptible population(s). Finally, the results of the three steps above are then combined to produce an estimate of risk.

For natural hazards, risk assessment involves 1) hazard identification: to identify the potential hazards in the investigation site. Some hazards are conjoint or causal (e.g., an earthquake may trigger landslides); 2) hazard probability: to derive the probabilities of the hazard magnitudes based on instrumental records, historical records or palaeo records. If insufficient information is available on site, regionalisation techniques could be used to extrapolate information from other sites; 3) consequence analysis: to work out expected losses from the realisation of the hazards. There are significant uncertainties with both the probabilities and potential losses. The chance of error in measuring these two variables is large. Risk with a large potential loss and a low probability of occurring is often treated differently from one with a low potential loss and a high likelihood of occurring. In theory, both are of nearly equal priority, but in practice it can be very difficult to manage.

5.6 Risk Management

Risk management is the identification, assessment, and prioritisation of risks followed by coordinated and economical application of resources to minimise, monitor, and control the probability and/or impact of unfortunate events or to maximise the realisation of opportunities (defined in ISO 31000 as the effect of uncertainty on objectives, whether positive or negative). Once risks have been identified and assessed, all techniques to manage the risk fall into one or more of these four major categories:

Avoidance: this includes not performing an activity that could carry risk (e.g., to avoid development in hazard prone areas such as flood plains or contaminated land). Avoidance may seem the answer to all risks, but avoiding risks also means losing out on the potential gain that accepting (retaining) the risk may have allowed (e.g., to build more homes).

Reduction: this involves reducing (or eliminating) the severity of the loss or the likelihood of the loss from occurring. There are two main measures on risk reduction: soft engineering measures (forecasting, land planning, policies) and hard engineering measures (e.g., structures). In engineering, the concept of return period is usually used to represent hazard probability. Return period is the average time interval between occurrences of a hazardous event of a given or greater magnitude, usually expressed in years. The optimum design return period for risk reduction can be determined by economic analysis if the probabilistic nature of a loading event (e.g., flood level) and the damage that will result if it occurs are both known over the feasible range of the loading event. As the design return period increases, the cost of the event mitigation measure increases, but the expected damage decreases because of the better protection provided. By summing up the project cost and the expected damage cost on an annual basis, a design return period having a minimum total cost can be found (Figure 5.3). A check dam is shown in Figure 5.4 to illustrate hard engineering measures for risk reduction.

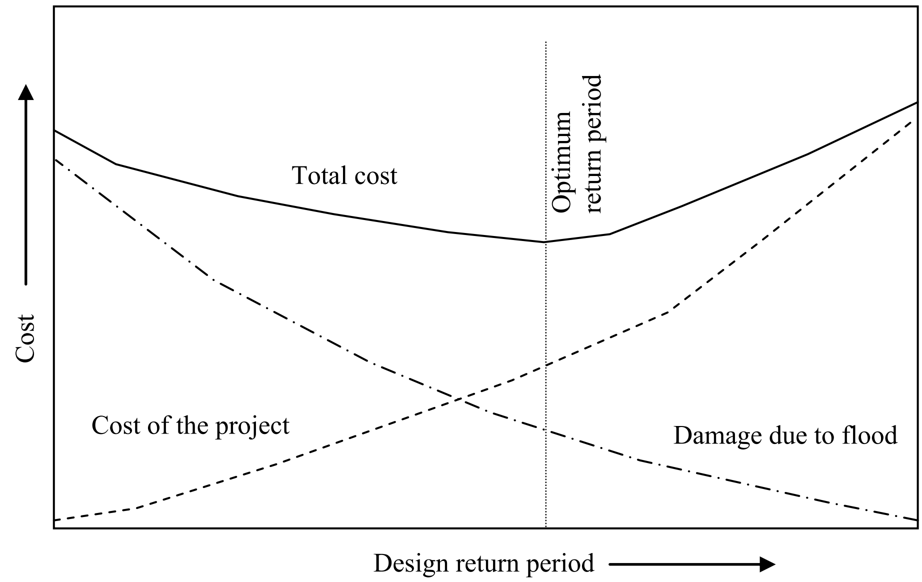

Figure 5.3 Optimum return period

Figure 5.4 Check dam for debris flows

Sharing: the burden of loss from a risk can be shared with another party, such as insurance firms.

Retention: the risk loss is accepted. This may be acceptable if the chance of a significant loss is rare and the cost to mitigate for the hazard is great (e.g., the hazard of collision of the Earth with a large asteroid).

5.7 Risk Communication

Risk communication is a complex cross-disciplinary academic field. Problems for risk communicators involve how to reach the intended audience, to make the risk comprehensible and relatable to other risks, how to pay appropriate respect to the audience's values related to the risk, how to predict the audience's response to the communication, etc. A main goal of risk communication is to improve collective and individual decision making. A flood warning system used in the UK is used here to illustrate flooding risk communication to the public. The type of flood warning service available varies greatly from country to country, and a location may receive warnings from more than one service. In the UK, the Met Office issues warnings of flooding likely to occur if their meteorological forecasts of rainfall indicate that heavy rainfall will occur - such forecasts might be available 6 to 24 hours or more before the predicted rainfall, but are not fully reliable as to whether or precisely where such rainfall will occur. In conjunction with this service, more location-specific flood warnings are the role of the Environment Agency (covering England and Wales) who undertake flood forecasting tasks over shorter lead-times. In the UK, the dissemination of flood warnings is moving or has moved towards a service whereby those potentially at risk of river flooding can pre-register to receive warnings by phone from an automatic system. Both warnings and updates about current conditions are also carried by local radio stations. In addition, internet sites have pages showing what locations have flood warnings in place and the severity of these warnings (Figure 5.5) (http://www.environment-agency.gov.uk/subjects/flood/floodwarning/). A telephone is also available for the general public to call.

Figure 5.5 Flood warning codes (Environment Agency)

5.8 Environmental Impact Assessment

Rachel Carson's book 'Silent Spring' (1962) awakened the world by showing the agricultural pesticides found in environments outside their target areas and the dire ecological consequences of introducing toxic chemicals into the natural food chains. As a result, government authorities were obliged to exert some control over the release of toxic chemicals into the environment and environmental assessment was accepted in principle at the United Nations Conference on the human environment in 1972. Nowadays, environmental impact assessment is widely practiced around the world to ensure that decision makers consider the ensuing environmental impacts when deciding whether to proceed with a project.

An environmental impact assessment is an assessment of the possible positive or negative impact that a proposed project (e.g., reservoir, wastewater treatment plant, highway) may have on the environment considering the environmental, social and economic aspects. The International Association for Impact Assessment (IAIA) defines an environmental impact assessment as "the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made."

Environmental impact assessment is divided into four steps: acquisition of information, analysis of information, communication of conclusions and selection of appropriate actions. The report of environmental impact assessment should have a logical structure and avoid repetition. The content should include the following information:

Project description: overview of the project, land use, emissions, etc.

Identification of stakeholder: to identify who are likely interested in or affected by the project.

Environment: to identify what components of the environment will be affected (human beings, flora, fauna, soil, surface water, groundwater, air, climate, noise, vibration, landscape, cultural heritage). The information from similar projects in the past should be consulted.

Impact prediction: prediction of impacts should be based on the collected data. Where possible, the prediction should be quantitative, albeit in many cases only qualitative predictions are possible.

Impact assessment: the significance of various impacts should be assessed. Relevant environmental standards may be used to judge the impact significance (e.g., noise standard, air quality standard).

Mitigation: approaches should be identified to minimise or avoid adverse environmental impacts as a result of the proposed project (e.g., monitoring, landscaping, site management, alternative hours of operation). The remaining or residual impacts should be assessed and dealt with if possible.

Public participation plays an important role in environmental impact assessment, which has several benefits: 1) it provides a chance to collect questions and concerns from the local people or organisations; 2) it allows the project team to explain the project details to the people concerned; and 3) it allows contentious issues to be discussed in an open forum.

Further reading materials

Kiely, G, 1997, Environmental Engineering, McGraw-Hill, England
Mihelcic, J.R. and Zimmerman, J.B., 2010, Environmental Engineering, John Wiley & Sons, Inc
Han, D., 2011, Flood risk assessment and management, Bentham
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6 Water Supply

Water supply is the provision of water for customers (e.g., domestic, trade, public, etc.) via a system of facilities (wells, pumps, aqueducts, reservoirs and water treatment plants, etc.). A water supply system involves water demand, water sources, water treatment and water distribution.

6.1 Water Demand

Human body is mainly made of water and will suffer from dehydration with inadequate water intake. The minimum water requirements for human water demand (to prevent dehydration) is defined by WHO (the World Health Organisation) as 3.7 litres/day for adult men and 2.7 litres/day for adult women (less needed for children). However, humans also need water for teeth brushing, toilet flushing and bathing, so normally a minimum 20 litres/day is needed for an adult person. For developed countries, the water demand is usually much higher than the minimum figure (e.g., car washing, garden irrigation). Some examples of total consumption figures (litres per person per day) are listed below

1. Highly industrialised cities (San Francisco, Philadelphia, ..)	600 - 700
2. Major cities (Glasgow, London,..)	400 - 500
3. Mixed cities with moderate industries (Liverpool, Plymouth, ..)	200-350
4. Mixed urban and rural areas with low proportion of industry (Brussels, ..)	150- 200
5. Small towns with little industrial demand	90-150

The water usage in Europe is generally less than North America. In the UK, the average daily household water consumption is 150 litres/person. Globally, 3800 km^3 of water are withdrawn per year with $2100km^3$ consumed (evaporated or incorporated in products) and $1700km^3$ return to local water bodies (as wastewater).

Estimation of water demand is needed for a new supply system or an upgrade to an existing system. A model is usually used to simulate the real system, which is either a macroscale model or microscale model. The macroscale model is used to estimate overall water demand and microscale model is used to plan the detailed pipe network system with pipe diameters and pumping system. Some factors on considering water demand are

Domestic (In-house use, out-of-house use)
Trade (Industrial, commercial, institutional, ...)
Agricultural
Public (public park, fire fighting, ...)
ecosystems
Losses(leakage)

The data to be collected include: climate data (rainfall and temperature which could influence water usage), historical water use (with different customer types), daily and seasonal water use patterns, predicted changes (land use, climate, demography), other factors (water price, water saving measures).

For residential areas, population is the most important factor in water demand estimation. To calculate the water demand in such areas (if the water source is from a water supply reservoir by damming a river),

$$Water\ demand = Safety\ factor \times (Abstraction\ rate + Compensation\ flow) \tag{6.1}$$

where

Abstraction rate (water abstracted from the river) = population´ water consumption
Population = the design population of the city to be supplied with water
Water consumption = water usage litres per capita per day
Compensation flow = the minimum flow to be released from the reservoir. Compensation water is the flow that must be discharged below a direct supply reservoir to compensate for the downstream water demand (people and ecosystems).

In addition to the average water demand estimation, daily and seasonal variations should also be considered so that the system is able to cope with a range of expected flows (from the minimum flow to the maximum flow). Daily variations are much easier to handle than seasonal variations.

6.2 Water Availability

The combination of water demand and water availability influences water supply. Water scarcity occurs where there is insufficient water to satisfy normal human requirements. The availability of water depends on the sources of water. The four commonly considered water sources are

Surface water: from streams, rivers, lakes, canals, reservoirs. Surface water is easy to abstract, but easy to contaminate, high in suspended solid (TSS) and pathogens.

Groundwater: from aquifers accessible by wells. Groundwater is low in suspended solid (TSS) due to soil filtering, high in dissolved solid (TDS), not easy to recharge, and difficult to clean up if polluted.

Seawater: obtained through desalination. There are many ways in desalinating seawater and the four popular ones are: distillation, reverse osmosis, electrodialysis and ion exchange. The most widely adopted systems are distillation and reverse osmosis using membrane (more energy efficient than distillation and becoming more popular). Desalinating seawater is high in cost, energy demanding and problematic in disposing brine wastewater. It may be suitable for areas near the coast.

Reclaimed and reused water: from former wastewater treated to remove solids and certain impurities. Instead of being discharged into surface water bodies such as rivers and oceans, it is used in irrigation, landscaping, groundwater recharge, indirect portable water, etc.

Hydrology is the study of water movement and distribution. Assessment of water resources at a region is based on hydrological analysis of various components of the hydrological cycle, which is a huge subject in itself. Due to the space limit in this book, a case on water availability for water supply reservoir design is briefly introduced here.

To evaluate the hydrological feasibility of a potential dam site for a water supply reservoir, a comparison between the water demand and catchment yield is necessary to check if sufficient water is available at the chosen site. A yield is the portion of the precipitation on a catchment that can be collected for use.

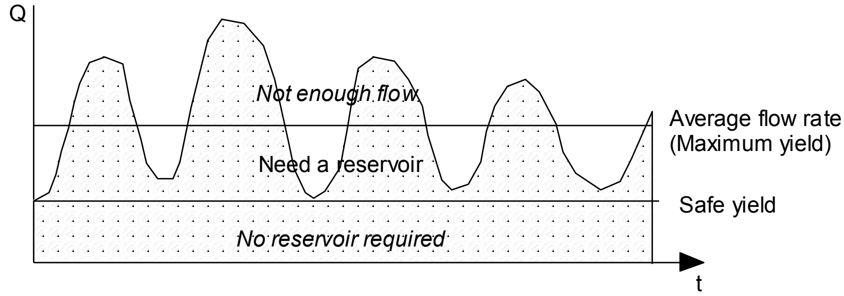

Figure 6.1 River hydrograph and Yield

Safe yield is the minimum yield recorded for a given past period. Abstraction is the intended or actual quantity of water withdrawn for use. Unless the minimum flow of a stream is well above the minimum abstraction which must be satisfied in a water supply project, the minimum flow must be supplemented by water impounded in a reservoir. The firm yield is the mean annual rate of release of water through the reservoir that can be guaranteed. Naturally, the larger the reservoir storage, the greater is the firm yield, with the limit that the firm yield can never be greater than the mean inflow to the reservoir (Figure 6.1). Since the firm yield can never be determined with certainty, it is better to treat yield in probabilistic terms. If the flow were absolutely constant, no reservoir would be required; but, as variability of the flow increases, the required reservoir capacity increases. This is another way of saying that a reservoir does not make water but merely permits its redistribution with respect to time.

A reservoir is used to retain excess water from periods of high flow for use during periods of low flow (Figure 6.2). The impounding reservoirs have two functions: a) to impound water for beneficial use and b) to attenuate flood flows. An impounding reservoir presents a water surface for evaporation, and this loss should be considered for yield estimation. In addition, the possibility of large seepage losses should also be considered. People and ecosystem downstream should be entitled to have a certain amount of water that they may make their accustomed use of (as compensation flow). Therefore, the compensation flow must be added to the abstraction or subtracted from the stream flow in calculating reservoir storage capacities.

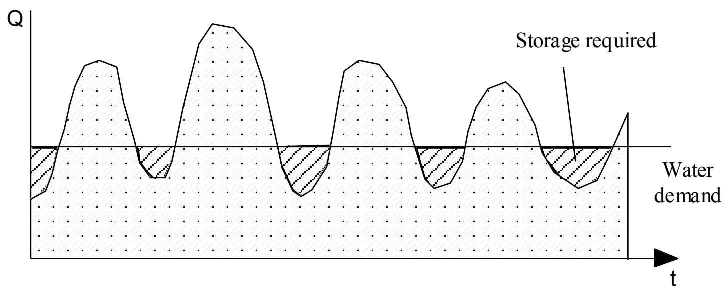

Figure 6.2 Reservoir storage required

There are three approaches that could be used to estimate the required reservoir storage.

a) Mass curve method (Rippl Diagram)

This method was developed by an Australian engineer in the 1890's to provide an answer to the question "… how big a reservoir is required for a given demand given an historic inflow sequence?"

A mass curve of supply is a curve showing the total (cumulative) volume entering a reservoir site over a certain time period (usually years) as shown in Figure 6.3. Records are examined for critical dry periods and the mass curve may be constructed for multiple years. Flow data at monthly increments are usually sufficient.

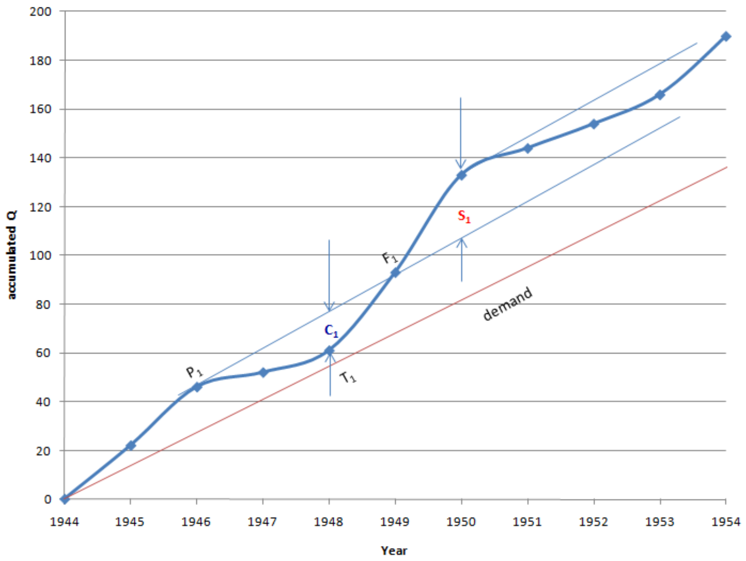

Figure 6.3 Mass curve (Rippl Diagram)

b) Water balance method

This method is similar to the Mass Curve method which is also based on the past flow records. Instead of using a graph to derive reservoir storage information, water balance is applied with a table to solve the reservoir storage and spillage problem. Table 6.1 is for illustration only and there are many alternative ways to construct a water balance table.

Table 6.1 Water balance table

No	Year	Q (m3/s)	demand	diff	accumulated	spillage	water in reservoir
0	1944	0	0	0	0		0
1	1945	22	13.6	8.4	8.4		8.4
2	1946	24	13.6	10.4	18.8	3.3	15.5
3	1947	6	13.6	-7.6	7.9		7.9
4	1948	9	13.6	-4.6	3.3		3.3
5	1949	32	13.6	18.4	21.7	6.2	15.5
6	1950	40	13.6	26.4	41.9	26.4	15.5
7	1951	11	13.6	-2.6	12.9		12.9
8	1952	10	13.6	-3.6	9.3		9.3
9	1953	12	13.6	-1.6	7.7		7.7
10	1954	24	13.6	10.4	18.1	2.6	15.5

c) Synthetic minimum flow method

This method is based on probability analysis and synthetic flow data instead of the real flow data are used in the storage estimation. The procedure is formed as follows: 1) locate a long monthly flow record; 2) select the lowest monthly flows in each year; 3) rank the minimum monthly values starting with the driest; 4) convert flow in m^3/s to m^3 (i.e., flow rate into runoff volume); 5) calculate the return period by $T = (n+1)/m$ (In n year record, a record has been equal to or exceeded for m times); 6) the return periods should be plotted on a logarithmic paper; 7) draw a line that can best fit the data points; 8) read the value of 100 year return period (or any other return periods depending the required reliability) from the fitted line. If 100 year return period is chosen, the reservoir has to satisfy the water demand in a dry month with 100 year return period. In addition, the following month(s) might be very dry as well and the designers have to consider longer periods than just one dry month, so 2, or 3 or more months should be considered in the design (up to 11 months in most projects). By repeating the procedures described above, it is possible to obtain a diagram as shown in Figure 6.4 and the flow values in 1, 2 , 3, 4, , …, 10, 11 months.

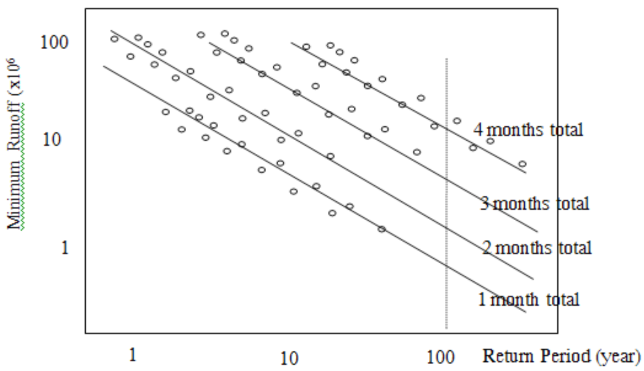

Figure 6.4 1, 2,3, …, 11 month droughts (the logarithmic plot)

A synthetic mass curve can then be constructed from the cumulative minimum runoff data as shown in Figure 6.5. Each point is read from the logarithmic plots. If water demand is known, strike a tangent line (with the slope of the water demand) to the curve and the required storage can be found on the negative ordinate.

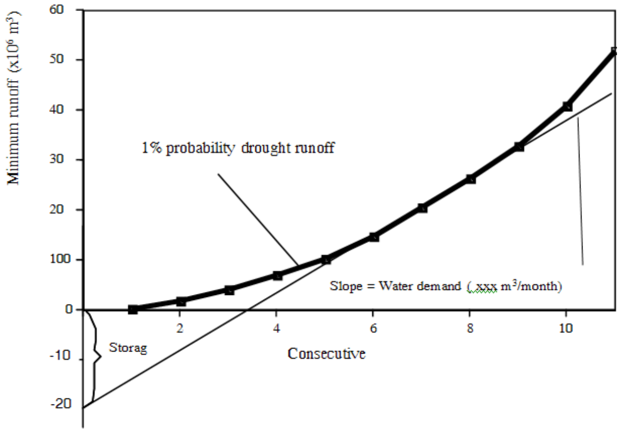

Figure 6.5 Minimum Runoff Diagram (for each dam site)

6.3 Water Treatment

Water treatment is a system to make water acceptable for a desired usage, such as drinking water, industrial utilisation, etc. The water treatment process is to remove or reduce contaminates in the water to meet the required levels. In the case of drinking water, it should be potable and palatable. '***Potable***' means water is healthy for human consumption (i.e., safe) without harmful microorganisms and organic/inorganic compounds that could cause adverse physiological effects. '***Palatable***' refers to water that is free from turbidity, colour, odour and objectionable taste. Natural water usually contains various chemical and biological constituents.

6.3.1 Characteristics of Water

Physical characteristics: used to characterise the water appearance. ***Turbidity*** measures water clarity (in NTU, nephelometric unit) and 5 NTU is the upper limit recommended by WHO. ***Colour*** is measured by apparent colour (unfiltered) or true colour (filtered by a 40 μm screen so that the colour is mainly from dissolved constituents). ***Particles*** are measured by quantity and sizes (1 to 60 μm). They are generally not visible by eyes and may adsorb toxic metals or synthetic organic chemicals. Particles are called suspended solids if their sizes are >1 μm, colloidal particles if sizes are in 0.001-1 μm and dissolved particles if sizes are <0.001 μm. ***Taste*** and ***odour*** come from dissolved organic/inorganic constituents and biological sources (e.g., decayed algae). Water ***temperature*** is very important and changes with seasons, which affects water physical, chemical and biological properties.

Chemical characteristics: used to describe various chemical constituents in water. ***Calcium*** is abundant in water and is a major constituent of water hardness (with magnesium). ***Chloride*** concentration can be high if water source is contaminated by brine water. ***Fluoride*** may exist in natural water or may be added artificially in some areas. ***Iron*** is frequently found in water and can create a brownish colour to bathroom fixtures. ***Nitrate*** (and other forms of nitrogen) may be found in surface and groundwater from urban and agricultural runoff (e.g., from ammonia fertilisers). ***Sulphur*** may occur as sulphates and reduced sulphides (in groundwater with low dissolved oxygen). ***Arsenic*** is widespread in the world, and is most serious in Bangladesh and India with hand-pimped wells. For organic constituents, ***natural organic matter*** (NOM) is derived from degraded vegetation and measured as ***total organic carbon*** (TOC). ***Synthetic organic chemicals*** (SOCs) are due to industrial activities, urban runoff, etc.

Biological characteristics: used to describe pathogenic microorganisms. ***Pathogens*** include many classes of microorganisms such as bacteria, viruses, protozoa and helminths, which cause sickness or disease in their hosts. Since there are many different pathogens, it is not practical to monitor all of them. In reality, indicator organisms are identified and used in checking biological water quality. The commonly used ones are total coliforms, fecal coliform and E. coli. Clearly, although indicator organisms can usually provide a good indication of water biological quality, they cannot prove the water is safe and other methods must be used to confirm the absence of various pathogens if in doubts.

6.3.2 Water Quality Standards

The ideal drinking water quality standards should be based on health and risk assessment information (i.e., how much of the contaminant may be present with no adverse health effects). However, costs and availability of technology are usually considered for legally enforced standards (cost benefit analysis and available technology). Therefore there are no universally accepted standard in the world. Currently, USA, EU and WHO have set three leading standards.

In the USA, the ideal drinking water standard under the Safe Drinking Water act is called ***MCLGs*** (maximum contaminant level goals) and the enforceable standard is called ***MCLs*** (maximum contaminant levels). MCLs should be as close as possible to MCLGs. The levels are normally expressed as a concentration in milligrams or micrograms per litre. For some contaminants, a treatment technique (***TT***) is set instead of an MCL. MCLs and TTs are the primary standards. More details can be found at the web site of the United States Environmental Protection Agency (2012). Some contaminants may have unpleasant tastes or odours without causing health problems and they are regulated by the secondary standards.

In the EU, the Drinking Water Directive specifies the quality of water intended for human consumption and is part of the regulation of water supply and sanitation in the EU. For the contaminant parameters, the EU directive applies the precautionary principle and many of them are more stringent than the USA and WHO standards, because the EU directive not only aims at protecting human health but also the environment.

The WHO standard is useful for those counties without their own legislative standards. It can be found by typing 'WHO Guidelines for drinking-water quality' in a search engine. A comparison among the standards from USA, EU and WHO can be found at Wikipedia 'Drinking water quality standards' (2012).

6.3.3 Treatment Processes

The water treatment processes include the following

Screen: coarse screens are firstly used to remove large solids such as tree branches and rubbish (about 100mm spacing). Finer screens are then used to remove fine solids or algae before other treatments.

Storage reservoir: for surface water sources during high flows with heavy silt load, it is useful to store raw water in a storage reservoir to improve water quality before further treatment.

Adsorption: this is a physical process to remove soluble molecules by the attachment to the absorbent surface. Adsorbents have very large surface areas available for adsorption. The most widely used adsorbent is activated carbon and others (activated alumina, clay colloids, hydroxides, etc.) Adsorption is used to remove algae, reduce colour, odour and organic matters. Carbon (from peat, coal, etc.) is activated by high temperature or chemicals (acid, strong base or a salt). Activated carbon is used either as a powder added to water or as granules packed as a filter.

Coagulation and flocculation: this is used to remove particles and a portion of dissolved organic matter. A coagulant is a chemical to reduce the repulsive forces among particles so that the attractive forces are able to gather particles together. The most commonly used coagulant is alum. Selection of coagulants is influenced by coagulant type, particle type and concentration, water temperature and pH, cost and availability, etc. Too little coagulant is insufficient to neutralise the negative charge in the particles and too much coagulant would turn negatively charged particles to positive, which are unable to destabilise the particles. Jar Test is used to work out the correct coagulant and its proper dosage for the tested raw water. Coagulant is dispersed into the water stream by rapid mixing systems (pumped, stirred tank or in-line static mixer). After the coagulation, flocculation is used to aggregate the destabilised particles in order to form larger particles (i.e., floc), and is carried out via a flocculation system (vertical shaft turbine, horizontal shaft paddle wheel or hydraulic system).

Hardness removal: water with high mineral content is called hard water. Water hardness is usually measured by the total concentration of calcium and magnesium. Hard water is generally not harmful to human health (in contrary, hard water may provide dietary calcium and magnesium and reduce the solubility of potentially toxic metal ions such as lead and copper). With hard water, soap solutions form a white precipitate instead of lather, which makes the solution less effective in washing dishes and clothes. Hard water can be softened by ion exchange and precipitation methods.

Sedimentation and filtration: large particles from coagulation and flocculation are removed by sedimentation and filtration. Sedimentation is the process in which the majority of the particles (include flocs) settle by gravity and are then removed. Filtration is used to remove small particles and pathogens. Two types of filtration include granular filtration and membrane filtration. Backwashing is regularly used to flush captured particles away from the filter.

Disinfection: disinfection is used to control the numbers of pathogens in water (bacteria and viruses) to reduce the risk of infection to an acceptable level instead of sterilisation (to kill all forms of microbial life). There are two activities which include primary disinfection (inactivation of microorganisms) and secondary disinfection (keeping a disinfectant residual in the treated water). Generally disinfectants are classified as oxidising agents (e.g., chlorine and ozone) and physical agents (heat or UV radiation). Ozone is powerful and expensive but with no residual action for secondary disinfection to protect the water during distribution. Chlorination is less powerful but cheaper with a lasting residual effect (the most commonly used approach). UV radiation is widely used for small water treatment plants and individual households. It has no residual action so it must be used close to the point of use.

6.4 Water Distribution

Treated water is sent to consumers by a water distribution system. The system uses a network of pipes (i.e., water mains) which include ***trunk mains*** and ***distribution mains***. Trunk mains are large pipes for transporting water from its source to a treatment plant and then to a service reservoir or tower. No branch or service pipes are connected to trunk mains. In contrast, distribution mains are the highly branched network with connections to individual houses. Underground pipes are usually coloured for easy identification (e.g., water is blue, gas is yellow, electricity is black and telephone is grey).

Water demand changes with time during day and night. It is costly to design the treatment plant to meet the maximum demand. Service reservoirs and water towers are used to smooth the outflow to the average flow from the treatment plant. They are also a useful reserve if the treatment plant or trunk main fails. A service reservoir may serve up to 50,000 people and provide a storage for at least one day's supply during the peak season. Individual households may have their own tanks to smooth the demand from the service reservoir.

Water pressures vary in different locations of a distribution system. Water tanks or towers may be used to maintain a suitable pressure range. Very high pressure is detrimental to plumbing fixtures and increases leakage. Low pressure results in a trickle of water at the tap and is insufficient for hydrant operations (required for fire fighting). Normally, water pressure should be between 30 - 75 meters of water head. A pressure regulator (or pressure reducer) may be used to allow high water pressure to be reduced to a safe value at each point where the water enters a building or a house.

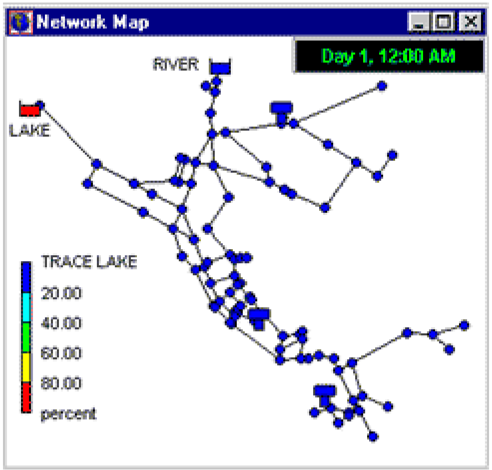

Figure 6.6 EPANET network map (EPANET, 2012)

EPANET is a software package developed by EPA for modelling water distribution piping systems. It is capable of performing extended-period simulation of the hydraulic and water quality behaviour within pressurised pipe networks. EPANET provides an integrated computer environment for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats. These include colour-coded network maps (Figure 6.6), data tables, time series graphs, and contour plots. EPANET is a public domain software package that is freely copied and distributed.

6.5 Wastewater

The used water from water customers needs to be collected for safe disposal, as a part of human sanitation systems. In a narrow sense, sanitation refers to the provision of facilities and services for the safe disposal of human urine and faeces. Inadequate sanitation is a major cause of disease world-wide and improving sanitation is known to have a significant beneficial impact on human health. In a broad sense, sanitation is the hygienic means of promoting health through prevention of human contact with the hazards of wastes, which can be physical, microbiological, biological or chemical agents, including human and animal urine and faeces, solid wastes, domestic wastewater, industrial wastes and agricultural wastes. Hygienic means of prevention could be engineering solutions (e.g. sewerage and wastewater treatment) or simple technologies (e.g. latrines, septic tanks).

Sewage includes household waste liquid from toilets, baths, showers, kitchens, sinks and so forth that is disposed of via sewers. The separation and draining of household waste into greywater and blackwater is becoming more common in the developed world, with greywater being permitted to be used for watering plants or recycled for flushing toilets. A sanitary sewer (also called a foul sewer) is a system specifically for transporting sewage from houses and commercial buildings to wastewater treatment plants. A separate drainage system is constructed to carry the stormwater runoff. Sewers carrying both sewage and stormwater together are called combined sewers and they were common in old urban sewage systems. Combined sewers require much larger and more expensive treatment facilities than sanitary sewers because precipitation causes widely varying flows, reducing wastewater treatment plant efficiency. In extreme cases, heavy volumes of stormwater runoff may overwhelm the wastewater treatment system, causing a spill (called Combined Sewer Overflows, i.e., CSO). Solutions to such a problem include CSO storage, wastewater treatment plant expansion, SuDS, and construction of a separate stormwater drainage system.

For stormwater drainage systems, as rainfall travels over roofs and the ground, it may pick up various contaminants including soil particles and other sediment, heavy metals, organic compounds, animal waste, and oil and grease. Fertiliser use on residential lawns, parks and golf courses is a significant source of nitrates and phosphorus in urban runoff, resulting in possible eutrophication in receiving water bodies. Most municipal storm sewer systems discharge stormwater, untreated, to streams, rivers or seas. Possible solution to such urban runoff problems include SuDS (Sustainable drainage systems) or/and some basic treatments before being discharged directly into receiving water bodies such as retention basins, wetlands, buried vaults with media filters, and vortex separators (to remove coarse solids).

Further reading materials

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7 Water Pollution

Water pollution refers to the introduction of a substance to the environment at levels leading to lost beneficial use of a resource or degradation of the health of humans, wild life or ecosystems. Pollution may be caused by ***point sources*** at stationary locations such as an effluent pipe or ***nonpoint sources*** (also called ***diffuse sources***) such as land runoff and the atmosphere. The mass flux of a pollutant is expressed as a ***load*** in mass per unit time.

7.1 Main Pollutants

Organic waste: Organic matters in water are composed of organic compounds. Generally, most carbon-containing compounds are organic (excluding steel and simple oxides of carbon). Organic compounds include natural compounds (e.g., living organism) which are capable of decay and synthetic compounds (e.g., plastics) which may not be biodegradable. Certain organic matters in water are a source of food for aquatic microorganisms that use dissolved oxygen to convert the organic matters into energy for growth and carbon dioxide & water. The microorganism population increases in proportion to the amount of organic matters. If microbial metabolism consumes dissolved oxygen faster than atmospheric oxygen can dissolve into the water, oxygen deficit will occur and aquatic life may die when oxygen is depleted by microbial metabolism. In rivers, oxygen depletion follows a special form as illustrated in Figure 7.1 named the dissolved oxygen sag curve. The oxygen concentration in the river drops rapidly following organic waste pollution. Later, as the organic matter is decomposed, the oxygen resources of the river are replenished. Not all organic matters can be decomposed by microorganisms and in contrast, nearly all organic matters can be fully oxidised to carbon dioxide with a strong oxidising agent under acidic conditions.

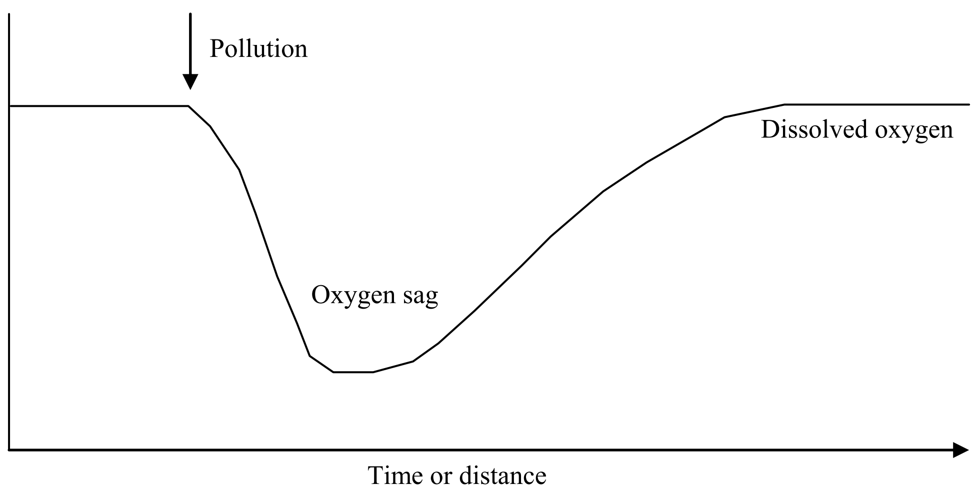

Figure 7.1 Dissolved oxygen sag curve

Many organic matters are synthetic and not biodegradable (termed ***refractory organic matters***). They include pesticides, detergents and petroleum hydrocarbons. Some pesticides and other refractory organics are the principal agents responsible for the decline of certain ecosystem species and are the threats to human health.

Suspended solids: solids in water may come from mining activities, river dredging, construction (e.g., road and bridge) and soil erosion. The increased turbidity reduces light penetration and depresses photosynthesis of ecosystems. Species diversity and abundance are affected.

Nutrients: nutrients (nitrogen, phosphorus, sulphur,…) in water encourages plant growth (usually in the form of algae). Those nutrients come from domestic, industrial and agricultural waste. Effluent from wastewater treatment plants may still contain large concentrations of nitrogen and phosphorus albeit sufficient treatment processes have been carried out. Diffuse pollution from agricultural waste is a major source of nutrients, especially nitrogen. Nutrient enriched water is more productive with excessive biological activities and water quality is usually significantly degraded (e.g., eutrophication).

Thermal pollution: industrial cooling processes (e.g., fossil and nuclear power plants) discharge heated water into water bodies with effects on reduced solubility of O_2 and altered speed of chemical reactions. Thermal pollution changes the natural temperature regime of a water system and the affected ecosystem could be stressed. Some aquatic species may die or are forced to relocate.

Toxic metals: they are metals that form poisonous soluble compounds. Toxicity is linked with solubility and is directly proportional to its ability to cause environmental damage. Metals, particularly heavy metals are toxic (e.g., mercury, lead, cadmium, arsenic). Lighter metals may also have toxicity, such as beryllium and on the other hand, not all heavy metals are toxic (e.g., iron, which is essential for life). Toxic metal pollutions have many sources, but most commonly arise from purification of metals, mining, irrigation with wastewater, vehicle exhaust emissions.

Pathogens and carcinogens: those are disease-causing microorganisms or cancer-causing substances including bacteria, viruses, protozoa, dioxins, etc. Domestic wastewater is responsible for many of the pathogens, and industrial and agricultural wastes are the usual sources for carcinogens.

Radioactive contamination: in the natural world, there is always radiation being emitted from radionuclides. Radioactive contamination refers to unintended or undesirable presence of radiative substances in water, usually from the leakage of stored radioactive materials or release from nuclear power plant accidents, etc.

7.2 Water Pollution Indicators

The indicators on water pollution are in three categories: physical (temperature, turbidity, total suspended/dissolved solids), chemical (pH, dissolved oxygen, nitrate, COD, BOD, pesticides, metals) and biological (EPT index, Trent biotic index) indicators. Most of them have been explained already in the book and only a few indicators are further explained here.

Oxygen saturation: the maximum amount of oxygen dissolved in water at a given temperature is called the saturation concentration. It is determined by Henry's law and varies from 14.6mg O_2/L at 0°C to 7.6 mg O_2/L at 30°C. As a result, fish with high oxygen demand prefer cold waters. The oxygen demanding wastes have greater impacts on water quality in the summer as well as during dry seasons since lower river flow has less capacity to dilute the waste. Under rare occasions, actual oxygen concentration may exceed the saturation value when algae and macrophytes are photosynthesising and producing dissolved oxygen. Such oversaturation is not stable and is eliminated when sufficient turbulence occurs. ***Dissolved oxygen*** (DO) can be measured by oxygen sensors (such as zirconia sensor, Clark-type electrode and Optodes).

Biochemical oxygen demand (BOD) is the amount of oxygen required by microorganisms to break down in organic matters. It is used as an indicator of organic pollution of water. BOD is expressed in mg O_2/L and can be measured in different ways. The most common method is carried out by mixing water sample with a small amount of microorganism seed (e.g., analogous to adding yeast to flour dough). The sample is tested to measure its dissolved oxygen (DO) before it is sealed in the dark to prevent further oxygen to be dissolved or generated by photosynthesis. After 5 day's incubation at 20°C, the dissolved oxygen is measured again and the difference between those two DO measurements is the BOD (initial DO - final DO). Dilution of the sample with oxygen saturated water may be used if organic matters in the sample are highly concentrated and the dilution ration should be included in the BOD calculation. Incubation durations other than 5 days have been tested before such as 1, 2, 5, 10 and 20 days and BOD_5 is commonly adopted which represents about 68% of the total BOD (in contrast, 90% of the BOD in 10 days and 99% of the total BOD in 20 days). BOD biosensor and software sensor are alternative measurement methods which are much faster (e.g., 30 minutes), but they are less reliable than the BOD_5 method. The BOD test results are normally with 10 or twenty percent uncertainties. If the water contains toxic chemicals capable of suppressing microbiological growth (e.g., industrial wastes, antibiotics in medical waste, commercial cleaning agent, chlorination disinfectant residuals), the BOD test results would be much lower. The amount and types of enzymes would also influence the BOD test results. In addition, some biodegradable organic matters can only degrade anaerobically such as cellulose and BOD test (depending on aerobic microorganisms) will not include those.

Typical BOD5 values: pristine water: up to 1mg/L; moderately polluted water: 2 to 8 mg/L; treated sewage (by three stages): up to 20 mg/L; untreated sewage: 600 mg/L in Europe and 200 mg/L in USA (due to the dilution from more water consumption).

Chemical oxygen demand (COD) measures organic matters which are both biodegradable and non-biodegradable, hence it covers a more broad spectrum of organic matters. As a result, the COD in a water sample is always higher the BOD. The ratio of COD/BOD provides a good indication to the proportion of organic matters that are biodegradable (COD/BOD usually varies from 1.25 to 2.50). In rivers, BOD gives a more useful estimate of the possible oxygen demand than COD and is more widely used as a measure of organic strength in the polluted water.

Biological indicators are useful to get a general reading of water quality without the high cost of lab scale analysis. Various indices are used to represent the states of macro-invertebrates. They are in two types: 1) pollution indices (existence or absence of indicator species); 2) diversity indices (to indicate the overall effect of all pollutants). However, biological indices are not always reliable. Factors other than pollution can affect the biological indices. Absence of some species may reflect its normal life cycle and quantitative sampling of biodiversity is difficult.

7.3 Wastewater Treatment

Wastewater treatment plants receive inflows from domestic, commercial, agricultural and industrial users, storm water runoff and infiltration. Industrial wastes may contain heavy metals, radioactive materials refractory organics, which may be treated on site following specific guidelines. Domestic wastewater is commonly treated in municipal wastewater treatment plants. A main purpose for wastewater treatment is to control pollution of a receiving water body (river, lake, groundwater, sea). Raw wastewater is highly polluted with about 0.5kg pollutants/m^3. The most common wastewater constituents include organic matters (measured by BOD and COD), suspended solids, pathogens (disease-causing microorganisms), nutrients (nitrogen and phosphorus), toxic chemicals (heavy metals, pesticides), and others (emerging chemicals such as perfumes, pharmaceuticals).

To design an effective treatment system, it is important to 1) identify the characteristics of raw wastewater; 2) set treatment objectives; 3) integrate unit treatment operations; 4) assess the system in view of green engineering, life cycle thinking and sustainability. From Google Maps, it is quite convenient to locate a wastewater treatment plant around cities (Figure 7.2).

Figure 7.2 Aerial view of wastewater treatment plant, Davyhulme, Manchester, UK (Google maps, 2012)

The treatment units include: pre-treatment, primary treatment, secondary treatment, tertiary treatment, disinfection and sludge treatment.

Pre-treatment: to remove coarse solids using screening, to remove grits using grit chambers, to remove fats and greases using flotation and to maintain a stable flow using an equalisation basin.

Primary treatment: to remove solids through gravity settling using ***settling (sedimentation) tanks*** (the removal rates are 60% suspended solids, 30% BOD, 20% phosphorus). Coagulants can be added at this stage to improve its effectiveness.

Secondary treatment: to remove dissolved organic matters using microorganisms (biological treatment). The most common biological treatment system is the ***activated sludge*** process. Effluent from primary treatment is sent to an ***aeration tank*** to be mixed with a diverse mass of microorganisms of bacteria, fungi, rotifers and protozoa. Oxygen is added to maintain the dissolved oxygen at 2mg/L by forcing air into the system (further higher level of oxygen would demand more energy to force the air without significant improvement to the system efficiency). After the process is finished, effluent is sent to the next stage and the settled sludge with microorganisms is removed from the system (with a small portion pumped to the aeration tank as microorganism seeds). At the end of this treatment, biologically degradable organic matters are decomposed and microorganisms are nutrient starved (or activated) as activated sludge. This process was first invented at Davyhulme sewage works in 1913 (Figure 7.1).

Tertiary treatment: mainly to remove nutrients such as nitrogen (N) and phosphorus (P). It has been found that 90% of total nitrogen and 75% of the total phosphorus from household effluent are found in urine and a dual sewer system to hand separate urine and faeces would help to reduce the cost in removing them in the combined wastewater. In a wastewater treatment plant, nitrogen is removed by nitrification (ammonia->nitrite ->nitrate) and denitrification (nitrate -> nitrogen gas) reactions. Phosphorus can be removed either biologically or chemically. In the enhanced biological phosphorus removal, specific bacteria (polyphosphate) are used to accumulate large quantities of phosphorus within their cells and these bacteria are separated from the treated water as a fertiliser. Alternatively, phosphorus can also be removed by chemical precipitation (such as alum). Chemical phosphorus removal is easier to operate and often more reliable than biological phosphorus removal.

Disinfection: to remove pathogenic microorganisms using ozone, chlorine, ultraviolet light, or sodium hypochlorite. Unlike drinking water, any disinfectant residual is not desirable in the effluent of a wastewater treatment plant. In the UK, ultraviolet light is widely used because of the concerns about the impacts of chlorine in chlorinating residual organics in the wastewater and in chlorinating organics in the receiving water.

Sludge treatment: to treat and store the sludge from the treatment processes. To reduce sludge unpleasing odour and pathogens, ***sludge stabilisation*** is carried out by either aerobic digestion (more energy demanding due to mechanical aeration) or anaerobic digestion (more popular due to its low energy cost and methane production). ***Dewatering*** is adopted to reduce the water in the sludge before disposal. A drying bed (with an underneath drainage system) is the simplest and cost-effective dewatering method. Mechanical devices can also be used to produce a sludge cake using belt squeezing or centrifugal force.

Disposal: dewatered sludge may be buried in a landfill (carbon sequestration), incinerated (with a potential problem in air pollution), applied to agricultural land (as fertiliser). Tight control of hazardous waste from industries and households is needed to prevent harmful contamination of the sludge. Pathogens in the sludge should be controlled by heating or chemical treatment if it is applied to areas open to the public (e.g., city parks).

Natural treatment system: wetlands are an alternative wastewater treatment method. A wetland uses soil-water-air-vegetation environment to treat wastewater. Wastewater should be treated by a primary system to remove the influent solids (by settling) before it is treated in a wetland. 'Living Machine' is a trademark and brand name for a ecological wastewater treatment system designed to mimic the cleansing functions of wetlands. Aquatic and wetland plants, bacteria, algae, protozoa, plankton, snails and other organisms are used in the system to provide specific cleansing or trophic functions.

Septic tank: A septic tank is a small-scale sewage treatment system in areas with no connection to main sewage pipes, usually in suburbs and small towns as well as rural areas. The term "septic" refers to the anaerobic bacterial environment that develops in the tank to decompose or mineralise the waste discharged into the tank. A septic tank generally consists of a tank connected to an inlet wastewater pipe at one end and a septic drain field at the other. Septic tank requires no power. A properly designed and normally operated septic system is odour-free. Waste left by the anaerobic digestion has to be removed from the septic tank by pumping, which is taken every a few years (some are up to 20 years). In areas with high population density, groundwater pollution from septic tanks may be a problem.

7. 4 Water Quality Modelling

Water quality models are used to analyse environmental systems and predict water quality changes due to modifications in catchments and wastewater treatment plants. The prediction provides a basis for engineers to carry out economic analysis to evaluate various options to improve the environment.

Water quality models are based on 1) the law of conservation of mass (material transport into and out of the control volume as a physical process) and 2) the change of substances in the control volume (transformation of the substances due to biological and/or chemical processes). Material transport refers to the movement of the substances from one point to another, which involves ***advection*** (movement with the fluid) and ***diffusion*** or ***dispersion*** (spread in the fluid due to differences in concentration).

The following water quality models are widely used:
AQUATOX - (Linking water quality and aquatic life) supported by EPA. This is a simulation model for aquatic systems and is used to predict the fate of various pollutants, such as nutrients and organic chemicals, and their effects on the ecosystem, including fish, invertebrates, and aquatic plants. It can be downloaded at
http://water.epa.gov/scitech/datait/models/aquatox/index.cfm

BASINS (Better Assessment Science Integrating point and Nonpoint Sources) supported by EPA. It is a multipurpose environmental analysis system designed for watershed and water quality-based studies. The software includes the open-source MapWindow GIS interface, a Data Download Tool, project builder, watershed delineation routines, and data analysis and model output visualisation tools. It also includes plug-in interfaces for well-known watershed and water quality models SWMM5, WASP7, and SWAT 2005. The software can be downloaded at
http://water.epa.gov/scitech/datait/models/basins/index.cfm

QUAL2K -(River and Stream Water Quality Model) supported by EPA. It covers one dimensional river channel with conventional pollutants (nitrogen, phosphorus, dissolved oxygen, BOD, sediment oxygen demand, algae), pH, periphyton and pathogens. The software can be downloaded at http://www.epa.gov/athens/wwqtsc/html/qual2k.html

SPARROW developed by USGS - a surface water-quality modeling tool for the regional interpretation of water-quality monitoring data. The model relates in-stream water-quality measurements to spatially referenced characteristics of catchments, including contaminant sources and factors influencing terrestrial and aquatic transport. SPARROW empirically estimates the origin and fate of contaminants in river networks and quantifies uncertainties in model predictions. The SPARROW model code is written in SAS Macro Language so it requires the SAS (Statistical Analysis System Institute) software components. The software can be downloaded freely at http://water.usgs.gov/nawqa/sparrow/

SWMM (Storm Water Management Model (SWMM) supported by EPA. SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of subcatchment areas on which rainfall-runoff is generated. The routing portion of SWMM transports this runoff through a conveyance system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps. It can be downloaded at http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/

WASP (Water Quality Analysis Simulation Program) supported by EPA. This model helps users interpret and predict water quality responses to natural phenomena and manmade pollution for various pollution management decisions. WASP is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. The time varying processes of advection, dispersion, point and diffuse mass loading and boundary exchange are represented in the model. WASP can be linked with hydrodynamic and sediment transport models that can provide flows, depths velocities, temperature, salinity and sediment fluxes. It can be downloaded at http://www.epa.gov/athens/wwqtsc/html/wasp.html

7. 5 Water Quality Standards for Pollution Management

Water pollution is usually managed by following water quality standards. Water quality standards are established by legal authority to define the level of pollutants allowed in a water system. There are three types of standards: ***receiving water standards*** and ***effluent standards***. Receiving water standards refer to water quality standards for receiving water bodies (rivers, lakes, sea waters) and effluent standards refer to the quality of effluents discharged to receiving waters. The aim of both types of standards is to achieve the desired quality of a water system. The receiving water standards consider the use of the water system (swimming, irrigation, drinking, industry). Effluent standards set the required maximum pollutant concentration to be achieved or degrees of treatment required before discharge. Both standards are regulated and should be met. Water quality standards must be reasonable so that dischargers should be able to achieve the standards through the available technology.

The European Community Water Framework Directive (2000/60/EC) (WFD) provides an integrated approach to the protection, improvement and sustainable use of Europe's rivers, lakes, estuaries, coastal waters and groundwater. WFD uses a holistic approach to managing the water cycle. The Directive defines 'surface water status' as the general expression of the status of a body of surface water, determined by the poorer of its ecological status and its chemical status. Thus, to achieve 'good surface water status' both the ecological status and the chemical status of a surface water body need to be at least 'good'. Ecological status refers to the quality of the structure and functioning of aquatic ecosystems of the surface waters. Good ecological status is defined locally as being lower than a theoretical reference point of pristine conditions, i.e. in the absence of anthropogenic influence. However, there are criticisms on WFD with the assumption that any anthropogenic influence is bad for an environment and a body of water polluted by natural occurring algae would be regarded as "good". This would prevent an anthropogenic clean-up operation. Another point is 'the theoretical reference point' doesn't take weather variations into account.

In the United States, water quality standards are created by state agencies for different types of water bodies and their desired uses. The Clean Water Act is the primary federal law in the United States governing water pollution. The act establishes the goals of eliminating releases of high amounts of toxic substances into water, eliminating additional water pollution, and ensuring that surface waters would meet standards necessary for human sports and recreation. The Clean Water Act does not directly address groundwater contamination and groundwater protection provisions are included in the Safe Drinking Water Act, Resource Conservation and Recovery Act, and the Superfund act.

Water quality regulated by ISO is covered in the section of ICS 13.060, ranging from water sampling, drinking water, industrial class water, sewage water, and examination of water for chemical, physical or biological properties. ICS 91.140.60 covers the standards of water supply systems.

Further reading materials

Gray, N.F., 1999, Water technology, Arnold
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Living Machine, 2012, http://www.livingmachines.com/
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8 Solid Waste Management

Solid wastes are defined as unwanted materials that are no longer of values to their owners (albeit they may be still of values to other parties). They are generated from various human and animal activities. Each year, billions of tones of solid wastes are generated which are in need of proper treatment. Improper management of solid wastes has direct adverse effects on human health and the environment (e.g., polluting rivers and groundwater sources and generating foul air).

8.1 Sources and Composition

The information on waste composition and generation rate is important for proper planning, treatment and disposal of solid wastes, which depends on their sources and types (Table 8.1). Some solid wastes (e.g., industrial, agricultural and mining) are managed by the waste producers. In this chapter, the focus is on the municipal solid wastes (MSW) which include residential, commercial, institutional, construction and demolition.

Table 8.1 Typical waste sources and types

Source	Description
Residential	Food wastes, garden wastes, paper, plastics, glass, metal, household hazardous wastes (homes)
Commercial & institutional	Similar to the residential wastes (shops, restaurants, offices, hotels, workshops, schools, hospitals, …)
Construction and demolition	Concrete, metals, wood, asphalt, soil, hazard wastes (building sites)
Industrial	relative homogeneous wastes such as metal, plastics, ashes, sands, paper, sludge, etc. (manufacturers, chemical plants, …)
Agricultural	manures, hazardous chemicals, spoiled food wastes (farms, dairies, …)
Mining	solid wastes (coal, metal, oil/gas, …)

Another way to classify wastes is to divide them into: biodegradable (spoiled food, green waste), recyclable (paper, glass bottles, cans), inert (construction and demolition waste), electrical and electronic (TVs, computers, screens, etc.), composite wastes (waste clothing, Tetra Packs, waste plastics such as toys), hazardous (paints, chemicals, fluorescent tubes, spray cans, fertiliser), toxic (pesticide, herbicides, fungicides), medical (pharmaceutical drugs).

As a rough rule of thumb, the residential waste generation in industrial countries is about 1 kg per person per day and the total MSW is about 1 tonne per person per year. The composition and quantities of solid wastes change with time and vary between different countries (and regions).

There several ways to collect solid waste information: 1) literature review (the information is collected from the past data in the literature); 2) input-output analysis (this is based on the consumption data to estimate wastes); 3) sampling survey (collection of actual data by sampling survey. It needs one or two years of survey to smooth out seasonal changes. A large number of samples are needed to reduce the uncertainty).

8.2 Waste Properties

Solid waste management options depend on physical and chemical characteristics of the waste. Waste generation rates are expressed in mass unit (e.g., kg/m^3) instead of volume unit. This is because waste densities vary greatly among the wastes with different compaction at different stages in the waste system (collection, storage and disposal). For example, the density for mixed loose MSW wastes is 90-180 kg/m^3, 300-420 kg/m^3 in compactor truck, 480-770 kg/m^3 in initial landfill and 700-1100 kg/m^3 in overburden landfill. Further details can be found in Diaz et al. 2003.

The moisture content of solid waste is

$$\text{moisture content} = \frac{\text{mass of moisture}}{\text{total mass of waste}} \tag{8.1}$$

and the dry mass weight can be found as

$$\text{dry mass} = \text{total mass of waste } (1 - \text{moisture content}) \tag{8.2}$$

The information on waste moisture content is used to derive dry mass of the received waste. In addition, for energy recovery design, it is important to know the energy content in wastes. Plastic and paper have high energy content and low moisture content. In contrast, garden wastes are less productive in energy release due to their high moisture content. The physical and chemical characteristics for some common solid wastes are listed in Table 8.2. It should be noted that the values in the table may vary significantly with local factors such as weather and season (e.g., garden waste's moisture content can change from 20% in dry autumn to 80% in wet summer after a rainfall event).

Table 8.2 Common physical and chemical characteristics of solid wastes

	Moisture content	Energy content as received	Energy content for dry mass	Carbon	Sulphur	Ash
	%	MJ/kg	MJ/kg	% by dry mass	% by dry mass	% by dry mass
Food	70	4.2	13.9	48	0.4	5
Magazines	4	12	12.7	33	0.1	23
Mixed paper	10	16	17.6	43	0.2	6
Mixed plastics	0.2	33	33.4	60	<0.1	10
Textiles	10	19	20.5	48	0.2	3
Rubber	1	25	25.6	70	1.6	20
Leather	10	17	18.7	60	0.4	10
Garden waste	60	6	15.1	46	0.3	6
Mixed wood	20	15	19.3	50	<0.1	1.5
Glass	2	0.2	0.2	0.5	<0.1	99
Metals	4	0.6	0.7	4.5	<0.1	91

(Source: selected from Tchobanoglous et al. 1993)

8.3 Solid Waste System

8.3.1 Storage, Collection and Transport

This part of the waste system typically accounts for 40 to 80 percent of the total cost. For residential wastes, the most common collection method is kerbside. The wastes are usually segregated into different containers according to waste types (food, garden waste, recyclable) as shown in Figure 8.1. Different trucks may be used to collect those containers. Commercial and institutional wastes generally need larger storage containers and use a separate system for waste collection. Drop-off stations for recyclables are also a valuable part of a waste collection system where people can drop their wastes. They are more efficient for trucks to pick up at a few key points instead of travelling along all the streets to pick up individual household containers (Figure 8.2). For old cities with narrow roads or high density urban areas, the Automated Vacuum Collection (AVAC) system is able to transport waste at high speed through underground tunnels to a collection station where it is compacted and sealed in containers. When the container is full, it is transported away and emptied by trucks. The system cannot carry large items such as furniture, construction wastes or glass which may break apart and sends shards flying through the tubes. For large cities and towns, transfer stations are often used as places where local waste collection vehicles will deposit their waste cargo prior to loading into larger vehicles. These larger vehicles (specialised with higher efficiency for heavy load) will transport the waste to the end point of disposal in an incinerator, landfill, hazardous waste facility, or for recycling.

Figure 8.1 Waste containers for different waste types in Bristol, England
(Source, Bristol City Council, http://www.bristol.gov.uk/nav/recycling-and-waste)

Figure 8.2 A drop-off station in Bristol, England

Figure 8.3 The AVAC system
(Source http://www.envacgroup.com/)

8.3.2 Recycling

Recycling is to convert wastes into new products. It can reduce the consumption of fresh raw materials, energy usage, air pollution (from incineration) and water pollution (from landfill). Recyclable materials include glass, paper, metal, plastic, textiles, and electronics. Plastics recycling is very challenging due to a diverse range of plastic types. To help with plastics recycling, an international resin code is marked on most plastic products with numbers 1 to 7 (1: PET for soft drink and water bottles; 2: HDPE for milk bottles; 3: PVC for shampoo bottle, windows, and piping; 4: LDPE for shopping bags, squeezable bottles; 5: PP for syrup bottles and straws; 6: PS for egg cartons, compact disc cases; 7: all other plastics). Types 1 and 2 are the most commonly recycled. Wastepaper is of higher value when the paper fibres are longer and less contaminated by impurities (e.g., office papers are of higher value than glossy magazines). Aluminium is of high value due to the high energy required to process aluminium ore. Ferrous metals (iron, steel) have been traditionally recovered by scrap metal processors. Although the system to process waste glass into new glass is well developed, the large cost of transportation to a glass smelter could make it impractical. Some debris from construction and demolition could be reused (such as tiles, bricks)/recycled (metal, stone, concrete). Sometimes there is a limit on the times of recycling circles (e.g., materials such as paper pulp can only be recycled a few times before material degradation prevents further recycling).

Separation of recyclable wastes can be done either by machines or human. Magnets can separate ferrous metals. Papers and plastics may be separated by their differences in density and sizes using screens, shaking tables, burst of air and rotating sieves. Glass materials with different colours and aluminium materials can also be separated by machines. In many situations, people are still needed to aid the separation of waste materials (e.g., to pick up specific wastes from a conveyor). Materials to be recycled are either brought to a collection centre or picked up from the kerbside, then sorted, cleaned, and reprocessed into new materials bound for manufacturing. Successful recycling requires careful consideration of the processing capacity and the markets for the recycled goods (e.g., a potential demand for the recycled products). If neither of them exists, recycling is incomplete and in fact only "collection".

The cost-benefit of recycling is complex. Economically, a major benefit is the reduced landfill costs. Other benefits can be worked out by comparing the market cost of recyclable material to the cost of new raw materials. What is difficult to estimate is externalities, which are unpriced costs and benefits that accrue to individuals outside of market transactions, such as decreased air pollution and greenhouse gases from incineration, reduced hazardous waste leaching from landfills, reduced energy consumption, and reduced waste and resource consumption, etc. For example, creating a new piece of plastic may cause more pollution and be less sustainable than recycling a similar piece of plastic, but these factors will not be counted in market cost. A life cycle assessment can be used to determine the levels of externalities and decide whether the recycling may be worthwhile despite unfavourable market costs. Alternatively, legal means (such as a carbon tax) can be used to bring externalities into the market, so that the market cost of the material becomes close to the true cost.

8.3.3 Composting

Composting is a microbial process used to treat biodegradable wastes. This is similar to aerobic wastewater treatment. Composting has several purposes: 1) to reduce waste mass; 2) to reduce pollution potential; 3) to destroy pathogens; and 4) to produce compost as nutrients for gardens, landscaping and agriculture (organic farming).

This processing is suitable for garden waste, food waste, paperboard, etc. Composting organisms require four equally important things to work effectively: carbon (to produce heat by the microbial oxidation of carbon), nitrogen (to grow and reproduce more organisms), oxygen (for oxidising the carbon as part of the decomposition process) and water (to maintain activity without causing anaerobic conditions). The most efficient composting occurs with a carbon: nitrogen mix of about 30 to 1. Nearly all plant and animal materials have both carbon and nitrogen, but amounts vary widely. When one waste is not compostable on its own, its mixing with other materials may help to build a proper carbon : nitrogen mix, air porosity and pH.

Composting requires making a heap of wetted organic matter and waiting for the materials to break down into humus after a period of weeks or months. Modern composting is a multi-step, closely monitored process with measured inputs of water, air and well mixed organic materials. The decomposition process is aided by shredding the plant matter, adding water and ensuring proper aeration by regularly turning the mixture. Worms and fungi further break up the material. Aerobic bacteria manage the chemical process by converting the inputs into heat, carbon dioxide and ammonium. The ammonium is further converted by bacteria into plant-nourishing nitrites and nitrates through the process of nitrification. In addition to the traditional compost pile, various approaches have been developed to handle different composting processes, ingredients, locations, and applications for the composted product (Grub composting, Bokashi composting, Compost tea, Hügelkultur, Humanure and Vermicompost). Nowadays, industrial composting systems are increasingly being installed as a waste management alternative to landfills.

8.3.4 Incineration

Incineration (waste-to-energy, energy recovery) is a process to liberate the energy in waste by combustion. This is suitable for wastes with high energy content, low moisture content and low ash content, which include paper, plastics, textiles, rubber, leather and wood. Incineration produces two solid by-products: bottom ash (unburnt waste) and fly ash (suspended particulate matter). Both of them contain hazardous matters in need of careful management. Incinerators reduce the solid mass of the original waste by 80–85% and the volume by 95-96 %, therefore the requirement for landfill is significantly reduced.

Air pollution control is required to limit emissions of particulates, volatile metals, nitrous oxides and incomplete combustion products. It has been found that modern incineration plants emit fewer particles, hydrocarbons and less SO_2, CO and NO_x than coal-fired power plants, but still more than natural gas fired power plants. An aerial photo in Figure 8.4 illustrates the visible air pollution at the Edmonton Solid Waste Incineration Plant in London. Odour pollution can be a problem with old-style incinerators, but odours and dust are extremely well controlled in newer incineration plants. An issue that affects community relationships is the increased road traffic of waste collection vehicles to transport waste to the incinerator. This problem can be avoided to an extent through the transport of waste by rail from transfer stations and locating incinerators in industrial areas.

Incineration systems have high initial cost, but its operational cost can be offset by savings in waste transport, landfill and recovered energy. They are suitable for regions where land values, energy costs and transport costs are high. In the USA and EU, incineration is playing an increasing role in solid waste management. There are six commonly used incineration systems: 1) Mass-burn (for unsegregated solid wastes); 2) Modular (small incinerators for specific wastes such as medical wastes); 3) Refused-derived fuel (energy rich wastes as fuel to power plants); 4) Co-incineration (to combine with production waste); 5) Hazardous waste (pathogens and toxins destroyed by high temperature); and 6) Cement kilns (as fuel for cement production).

Figure 8.4 Edmonton Solid Waste Incineration Plant, London, England (Google map)
(Note: type 'Incineration Plant' in Google map and it may provide some sites near where you live)

8.3.5 Landfill

A landfill site is a site for the disposal of solid wastes by burial (Figure 8.5). This is the oldest form of waste treatment and the most common method for waste disposal in many places of the world. In a landfill, wastes are packed into solid forms and covered to insulate them from water and air (usually everyday with layers of soil). Leachate is a liquid drained from the landfill as a contaminated wastewater. In a new landfill with oxygen still available, organic matters decompose and carbon dioxide is produced. As time goes by, the remaining oxygen is consumed and an anaerobic condition leads to the production of methane gas.

Landfill involves siting, engineering design, construction, operation, monitoring and closure. Landfills should be located with a minimum risk to the environment and society (e.g., to avoid floodplains, active geological faults, drinking-water catchments, etc.). Geographical Information System (GIS) is a useful tool in helping design engineers in site selection. The landfill gas is a source of energy to produce electricity. The amount of methane produced from the landfill is about 100 L/kg. Half-lives for methane production vary widely depending on waste compositions (from 1 to 35 years). Although landfill is covered, small quantity of water may still be able to get through to produce leachate. Concentration of leachate constituents changes with time and is usually much higher than those in untreated urban sewage. Hydraulic barriers to cover and underlie the landfill should be constructed with compacted clay and geomembranes to limit the rainfall infiltration and leachate leaking. A collection system based on gravity is used to convey leachate to a sump within the landfill and then to be pumped out to a storage location. Landfill leachate is similar to urban sewage and the collected leachate should be sent to a wastewater treatment plant by pipe or truck. A landfill requires careful management over its lifetime aided by a sound monitoring system. In recent years, some countries, such as Germany, Austria, Belgium, the Netherlands, and Switzerland, have banned the disposal of untreated waste in landfills, and only the ashes from incineration or the stabilised output of mechanical biological treatment plants may still be deposited.

Figure 8.5 Cumberwell Landfill, England (Cumberwell Park Golf Course is built on the old landfill) (Source: Google Maps)

8.3.6 Alternative Technologies

In addition to the aforementioned traditional technologies, many new approaches are undergoing development. They include anaerobic digestion, alcohol/ethanol production, biodrying, gasification, in-vessel composting, mechanical biological treatment, mechanical heat treatment, plasma arc waste disposal, pyrolysis, tunnel composting, UASB (applied to solid wastes), and waste autoclave. Further details on them can be found in Wikipedia 'List of solid waste treatment technologies'.

8.4 Solid Waste Management

Solid waste management is a complex task and requires a systems approach. The combination of different components should be considered as a whole in a holistic way to serve the need of the current and future generations. Although economy of scale means larger landfills, incinerators and composting plants are more economically efficient, they would increase transport cost and are more likely to face public opposition. Consultation with stakeholders is an important step for any successful solid waste management. Stakeholders with direct and indirect interests in solid waste management may include neighbours, local communities, wider communities, media, government agencies and various social interest groups. Good policy should be developed by analysing policy options with assessment in costs and benefits, risks and unintended effects. The priority in a waste management policy is to reduce the wastes and followed by 'reuse' and 'recycle' (the 3 Rs). The three Rs are expanded in Europe into a waste hierarchy as shown in Figure 8.6 which classifies waste management strategies according to their desirability (reduce, reuse, recycle, recovery, and disposal).

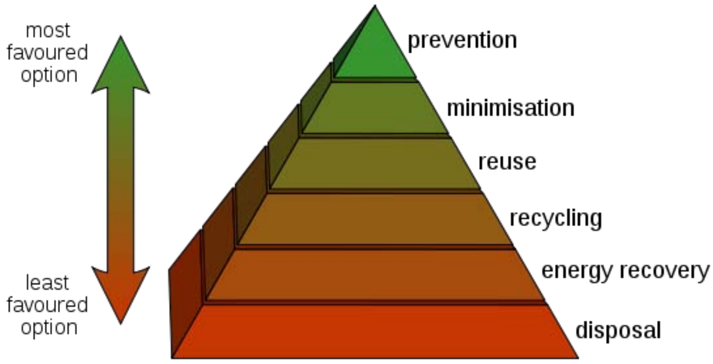

Figure 8.6 The waste hierarchy (Wikipedia 'Waste hierarchy')

Further reading materials

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9 Air Pollution

The Earth is surrounded by gases called air which forms the atmosphere. The atmosphere is a complex dynamic natural system essential to support life on the Earth. The air interacts with water and land. Acid rain falling on the ground is a result of air pollution. Many pollutants such as particulate matters, heavy metal, and ozone are able to influence water quality and ecosystem functions. On the other hand, polluted rivers/lakes and sewage systems can cause air pollution in their surrounding areas. Therefore, it is important for a water engineer to understand the air and its related quality issues, and vice versa for an air quality engineer to understand water pollutions.

9.1 Composition of Air

The composition of dry air is listed in Table 9.1. This table changes with time (e.g., CO_2 concentration has been in increase with time). Air also normally contains water vapour (variable, about 1% - 4% at surface), dust, pollen, spores, sea spray, volcanic ash, and various industrial pollutants. The greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone (bold formulas in Table 9.1). The air density at sea level is 1.2kg/m^3 and it decreases with the increasing height.

Table 9.1 Composition of Dry Air (NOAA, 2012)

Gas	Formula	Volume (parts per million)	Volume (%)
Nitrogen	N_2	780,840 ppm_v	78.1%
Oxygen	O_2	209,460 ppm_v	20.9%
Argon	Ar	9,340 ppm_v	0.93%
Carbon dioxide	**CO_2**	394.45 ppm_v	0.04%
Neon	Ne	18.18 ppm_v	0.002%
Helium	He	5.24 ppm_v	0.0005%
Methane	**CH_4**	1.79 ppm_v	0.0002%
Krypton	Kr	1.14 ppm_v	0.0001%
Hydrogen	H_2	0.55 ppm_v	0.00006%
Nitrous oxide	**N_2O**	0.3 ppm_v	0.00003%
Carbon monoxide	CO_2	0.1 ppm_v	0.00001%
Xenon	Xe	0.09 ppm_v	0.00001%
Ozone	**O_3**	0.0 to 0.07 ppm_v	0.000007%
Nitrogen dioxide	NO_2	0.02 ppm_v	0.000002%
Iodine	I_2	0.01 ppm_v	0.000001%
Ammonia	NH_3	trace	

9.2 Structure of the Atmosphere

The earth atmosphere has distinctive layers with a total mass of 5×10^{18} kg, three quarters of which is within the bottom 11 km. The atmosphere becomes progressively thinner with altitude without abrupt boundary. However, the Kármán line at an altitude of 100 kilometres above the Earth's sea level is commonly used as the boundary between the atmosphere and outer space. Beyond this altitude, the atmosphere becomes too thin to provide sufficient aerodynamic lift to support any aeronautical vehicles within the orbital speed of the earth.

The atmospheric is divided into several layers based on temperature profiles as shown in Figure 9.1.

Troposphere: it ranges from 9km at the poles to 17 km at the equators (it varies with seasons as well). This layer is heated by energy transfer from the ground surface and temperature decreases with altitude. It contains 80% of the atmospheric mass and 99% of its water vapour (supplied from the surface by evaporation and transpiration). Since saturation water vapour pressure decreases as temperature drops, the amount of water vapour in the atmosphere decreases with height.

In the lowest part of the troposphere, the planetary boundary layer (PBL) is directly influenced by its contact with the ground surface. Within PBL, the wind is affected by surface drag (hence turbulent) and moves across the isobars (while above PBL, the wind is along the isobars). The wind speed increases with the altitude in a power law form with a zero value at the ground surface due to the non-slip condition.

The turbulence causes vertical mixing in the air, which plays an important role in pollutant dispersion. PBL's depth varies widely between 50m (e.g., in a calm night) to 2000m (e.g., in a hot afternoon) with a typical value of 300m in mid-latitudes.

Stratosphere: it extends from the tropopause (the top of the troposphere) to about 50 km. In contrast to the troposphere, the temperature here increases with height due to increased absorption of ultraviolet radiation by the ozone layer. It has restricted turbulence and mixing due to its temperature profile (warmer air above colder air), hence it is dynamically stable (i.e., no regular convection and turbulence). Airliners usually fly at the bottom of the stratosphere to take advantage of the thin air for reduced drag and to avoid extreme turbulence in the troposphere.

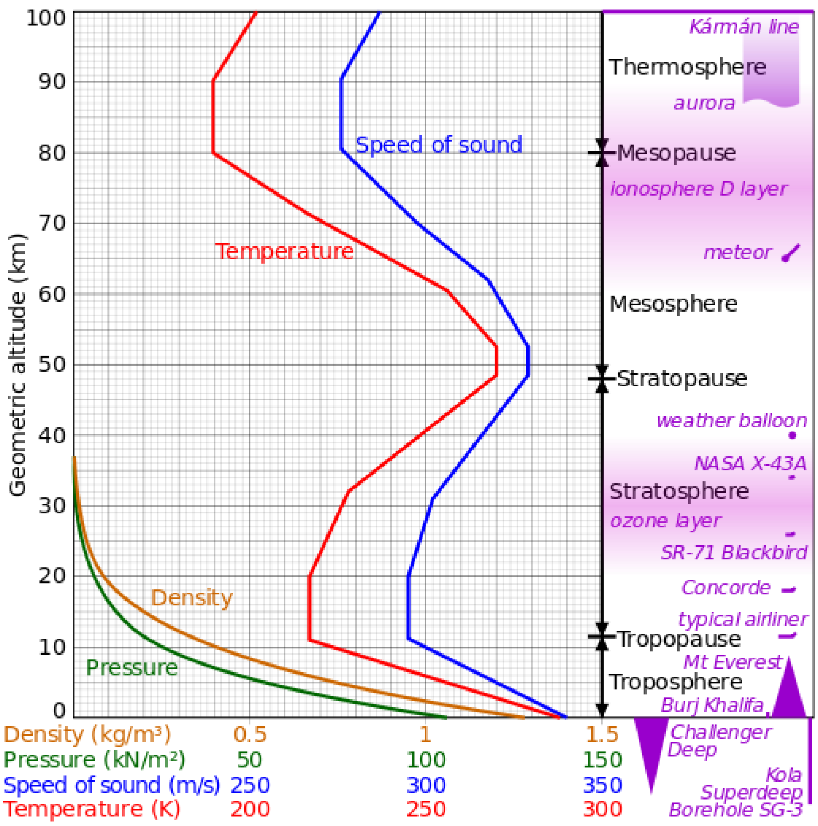


Figure 9.1 The US standard atmosphere (Wikipedia, 2012)

Mesosphere: this is from 50km to 80km with its temperature decreasing in height. Atmospheric tide, gravity wave and planetary wave are featured here. Millions of meteors collided with the earth are mostly melted or vaporised in this layer.

Thermosphere: it ranges from 80km to 350~800km (it varies with solar activity). The air is very thin here and stable with increasing temperature (up to 1500 °C).

9.3 Transport of Air

The movement of air is divided in two categories: the outdoor environment (ambient air) and indoor environment.

Global transport: among the layers of the atmosphere, the two layers near the Earth surface are more relevant to air pollution. The troposphere is the primary place to receive the pollution emissions from human and nature. The processes of transport and transformation influence the fate of the pollutant. Due to its stable temperature profile, there is little mixing in the stratosphere. The strong solar radiation (especially ultraviolet) in this layer converts oxygen (O_2) into ozone (O_3) by photochemical reaction to create the well known ozone layer. Over the globe, there exist large scale air movements as shown in Figure 9.2 due to uneven solar radiation distribution and rotation of the Earth. It can be seen that air does not obey geopolitical boundaries and air pollution can be trans-boundary.

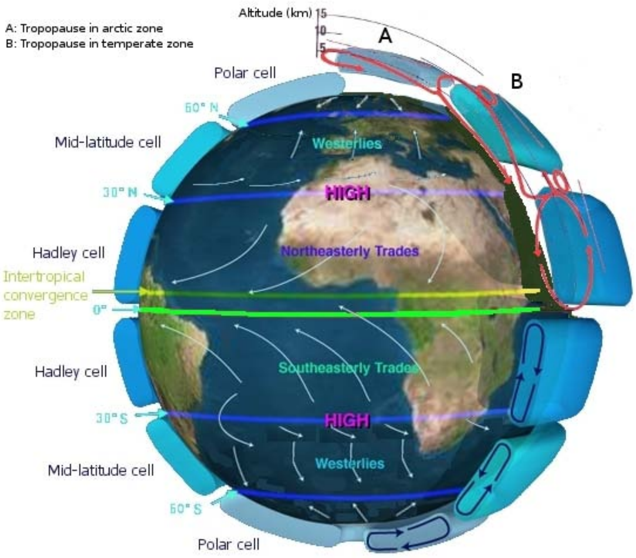


Figure 9.2 Global air circulation (Wikipedia, 2012)

Regional transport: high and low air pressures dominate regional air transport. Low pressure is created when air is warmed to rise by surface heating. High pressure is created when air descends to the ground. Air tends to move from a high pressure area to a low pressure area. In a low pressure region, air quality may improve due to dispersion and precipitation cleansing.

Local transport: due to the different temperatures between land and sea in the coastal area, the wind direction changes during the morning and evening as shown in Figure 9.3. In the morning, cleaner air moves to the land and is then polluted by human activities. Pollutant concentration increases as the air moves further inland. In the evening, the opposite wind movement occurs with the polluted air moves to the sea (and with its impact on the sea aquatic ecosystem). Understanding such a diurnal movement is important for coastal residents to cope with air pollution problems in the area.

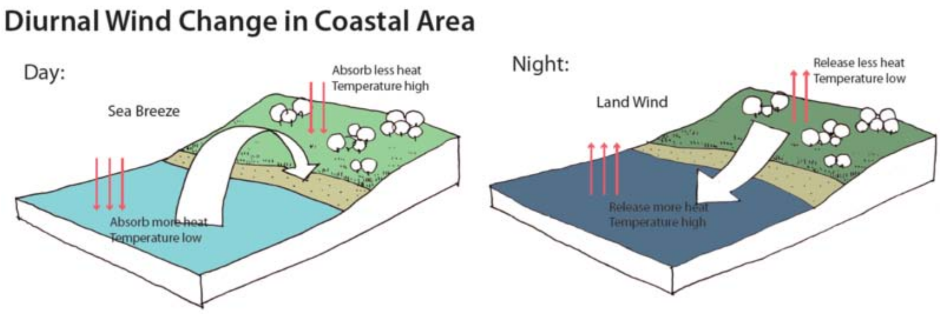


Figure 9.3 Diurnal wind change in coastal area (Wikipedia, 2012)

Indoor air: indoor air quality has a significant impact on human health. Design of ventilation system in a building influences temperature, humidity and pollutant movement. Natural ventilation systems use outdoor wind and differences of indoor/outdoor temperature. They are based on the pressure creased by outdoor air striking a building (positive on the windward and negative on the leeside), and the pressure caused by temperature differences in different parts of the building (warmer air is lighter than cold air). Such systems are usually suitable for mild or moderate climates with minimum ambient air pollution. In contrast, mechanical ventilation systems provide controlled ventilation to the building, usually coupled with heating, cooling and air pollution control. Such systems are called HVAC (Heating, Ventilation, Air Conditioning). If possible, natural ventilation should be preferred over mechanical ventilation.

9.4 Air Pollutants

Air pollution is the introduction of a substance (i.e., pollutant) in the air harmful to human and the environment, which may be natural (e.g., volcano eruption) or man-made. Pollutants can be solid, liquid or gaseous. The human health impact caused by air pollution may include difficulty in breathing, wheezing, coughing and aggravation of existing respiratory and cardiac conditions, which are reflected in increased medication use, increased doctor or emergency room visits, more hospital admissions and premature death. In the United Kingdom the Great Smog of 1952 formed over London killed 4000 people in six days and 8,000 more died within the following months.

Major pollutants include

Nitrogen dioxide (NO_2): this is a reddish-brown toxic gas with a characteristic sharp, biting odour. It is produced from fuel combustion that converts oxygen and nitrogen (78% of the air) to NO and then quickly to NO_2. Their combined presence is described as NO_x. They may cause breathing problems in sensitive people and react with water vapour to form nitric acid and fall as acid rain. NO_2 is also produced naturally during thunderstorms by electrical discharge. The WHO air quality standard for NO_2 is 200mg/m^3 (1 hour average) and 40mg/m^3 (annual average). The two thresholds represent both short term and long term effects of the pollutant on human health.

Sulphur dioxide (SO_2): since coal and petroleum often contain sulphur, their combustion generates sulphur dioxide. Many raw materials such as aluminium, copper and iron ores contain sulphur, and their extractions produce SO_2. Naturally, SO_2 is also produced by volcanoes. Like NO_2, SO_2 can be converted to sulphuric acid and fall as acid rain. SO_2 can accelerate the decay of building materials and cause respiratory disease and death. The WHO air quality standard for SO_2 is 20mg/m^3 (24 hour average) and 500mg/m^3 (10 minute average).

Particulate matter (PM): It refers to fine particles (solid or liquid) with diameter of 10 micrometres or less, which can be either man made or natural. Natural particulates include those from volcanoes, dust storms, forest and grassland fires, living vegetation, and sea spray. Man-made particulates are produced by the burning of fossil fuels in vehicles, power plants, construction and various industrial processes. They are not a uniform combination of compounds (acids, organic chemicals, metals, soils, etc). All particles with 10 mm or less in diameter are denoted as PM10 and those with 2.5mm or less in diameter are denoted as PM2.5. Large particles are problematic for the respiratory system because they are trapped in the upper respiratory system, producing clogged nose and scratchy throat. Fine particles make their way deeper into the lung to cause breathing problems and are absorbed into the bloodstream to affect many organs. The WHO air quality standard for PM_{10} is 50mg/m^3 (24 hr average) and 20 mg/m^3 (annual average), and for $PM_{2.5}$ is 25mg/m^3 (24 hr average) and 10 mg/m^3 (annual average). It is not clear about the health risk posed by particles with diameters less than 0.1mm and no standard is set for PM_1 at the moment.

Ground level ozone (O_3): it is produced by complex chemical reactions driven by sunlight. Reactive hydrocarbons (benzene, propane, components of gasoline) and nitrogen oxides (notably NO and NO_2) react under sunlight. The concentration of ozone builds up during the day with its peak in early afternoon (along with the air temperature). In the night, the ozone concentration drops when photochemical actions stops and ozone removing processes dominate. Ozone is a powerful oxidising agent readily reacting with other chemical compounds to make many possibly toxic oxides. Ozone is detrimental to ecosystems by damaging sensitive plants (and some crops) and reducing biodiversity. It is a strong respiratory irritant causing lung inflammation, breathing difficulties, aggravated asthma and permanent lung damage from repeated exposures. The WHO air quality standard for O_3 is 100mg/m^3 (8 hr average).

Carbon monoxide (CO): it is produced from incomplete combustion of fuels and vehicular exhaust is a major source of carbon monoxide. CO is colourless, odourless, non-irritating but very poisonous. It can be easily absorbed into blood and may impair victim's ability to function and lead to cardiovascular problems. At high levels, asphyxiation can occur in indoor environment due to poor heating system and inadequate ventilation. The WHO air quality standard for CO is 30mg/m^3(1 hr average) and 10mg/m^3(8 hr average).

Others: there are also many other pollutants in the air such as odours, radioactive pollutants, volatile organic compounds, carbon dioxide (CO_2), Chlorofluorocarbons (CFCs), ammonia (NH_3), peroxyacetyl nitrate (PAN), persistent organic pollutants (POPs), toxic metals (lead, cadmium, copper), etc.

All major pollutants are routinely measured by the relevant government agencies. Figure 9.4 shows the real-time air quality monitoring sites in the UK and the general public can access the measured air quality data by clicking the interested sites on the screen. An overview of the current state of air pollution health bandings is displayed for a quick scan.

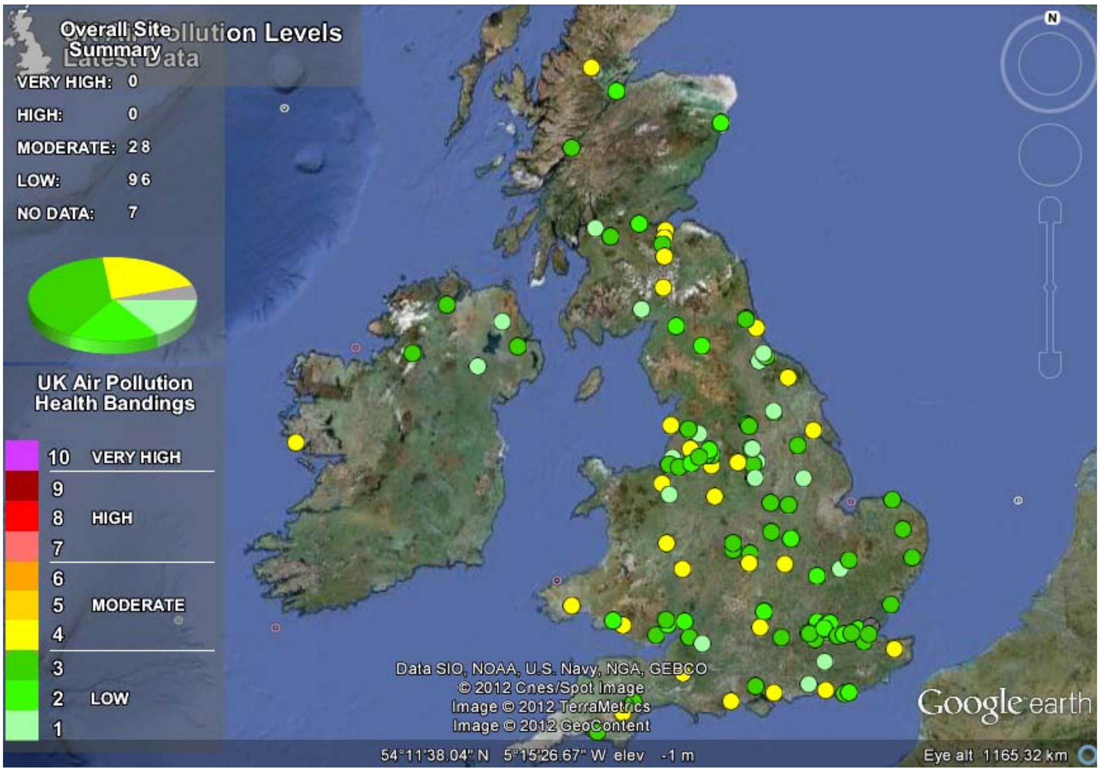


Figure 9.4 Air quality monitoring sites in the UK (Google Earth, 2012)
(http://uk-air.defra.gov.uk/latest/google-earth)

9.5 Emission Estimation and Control

Emission is the amount of pollutant a source releases into the air. Emission rate is expressed as mass per time, such as g/s, kg/day or tonnes/year. Emission rate and pollution composition can change with time. Air pollutants are sources from four main types: 1) point source (a single, identifiable source of air pollutant emissions such as a single furnace); 2) line source (one-dimensional source of air pollutant emissions such as a line of vehicles on a road); 3) area source (a two-dimensional source of diffuse air pollutant emissions such as forest fire and land fill); and 4) volume source (a three-dimensional source of diffuse air pollutant emissions usually found in oil refineries). They may also be divided as stationary and mobile (e.g., cars).

There are five methods to quantify air pollutant emissions: 1) direct measurement (either stationary sensors or mobile sensors); 2) mass balance (an indirect way by the conservation of mass from the difference between the measured inflow and outflow in a system); 3) process modelling (by mathematical modelling of physical and chemical processes); 4) emission factor modelling (emission factor is the ratio of emission and pollutant source intensity and can be found in the published manual. The source intensity such as kg/day times its relevant emission factor to derive the estimated emission rate); 5) expert judgement (subjective estimation by experience and knowledge). The reliability and cost are ranked from high to low with the method 1 to 5 (i.e., Method 1 is the most reliable and most costly and Method 5 is the least costly and least reliable).

There five options to control air pollution: 1) prevention (green chemistry, green engineering); 2) regulatory solutions (permit for allowable emissions, monitoring); 3) market solutions (a total allowable emission cap is set and emission allowances can be traded in the market); 4) voluntary solutions (voluntary emission reduction by individuals, communities and firms encouraged by easy access of air quality information); and 5) emission control technologies (thermal oxidiser to oxidise pollutants using high temperature in a similar way to incinerators, absorption by passing polluted air through water soaked media in a similar way to a smoking waterpipe, biofilter filled with a biological medium for the polluted air to be passed through to interact with the attached microorganisms, and particulate emission control technologies such as cyclone, scrubber, baghouse and electrostatic precipitator).

For easy public understanding, air quality may be indicated by Air Quality Index (AQI) or Air Pollution Index (API). In the USA, AQI is based on O_3, $PM_{2.5}$, PM_{10}, NO_2, SO_2 and CO (EPA, www.airnow.gov). AQI is classified into 6 bands: Good (0), Moderate (100), Unhealthy for sensitive groups (150), Unhealthy (200), Very Unhealthy (300), Hazardous (500). In the UK, air pollution is described on a scale of 1-10 where 1 corresponds to 'Low' pollution and 10 corresponds to 'Very High' pollution (http://uk-air.defra.gov.uk/air-pollution/). The overall air pollution index for a site or region is determined by the highest concentration of five pollutants: O_3, $PM_{2.5}$, PM_{10}, NO_2 and SO_2. Table 9.2 illustrates the air quality information for the public.

Table 9.2 UK Air Index Table (http://uk-air.defra.gov.uk/air-pollution/daqi)

Air Pollution Banding	Value	Accompanying health messages for at-risk groups and the general population	
		At-risk individuals*	**General population**
Low	1-3	**Enjoy** your usual outdoor activities.	**Enjoy** your usual outdoor activities.
Moderate	4-6	Adults and children with lung problems, and adults with heart problems, **who experience symptoms**, should **consider reducing** strenuous physical activity, particularly outdoors.	**Enjoy** your usual outdoor activities.
High	7-9	Adults and children with lung problems, and adults with heart problems, should **reduce** strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms. People with asthma may find they need to use their reliever inhaler more often. Older people should also **reduce** physical exertion.	Anyone experiencing discomfort such as sore eyes, cough or sore throat should **consider reducing** activity, particularly outdoors.
Very High	10	Adults and children with lung problems, adults with heart problems, and older people, should **avoid** strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often.	**Reduce** physical exertion, particularly outdoors, especially if you experience symptoms such as cough or sore throat.

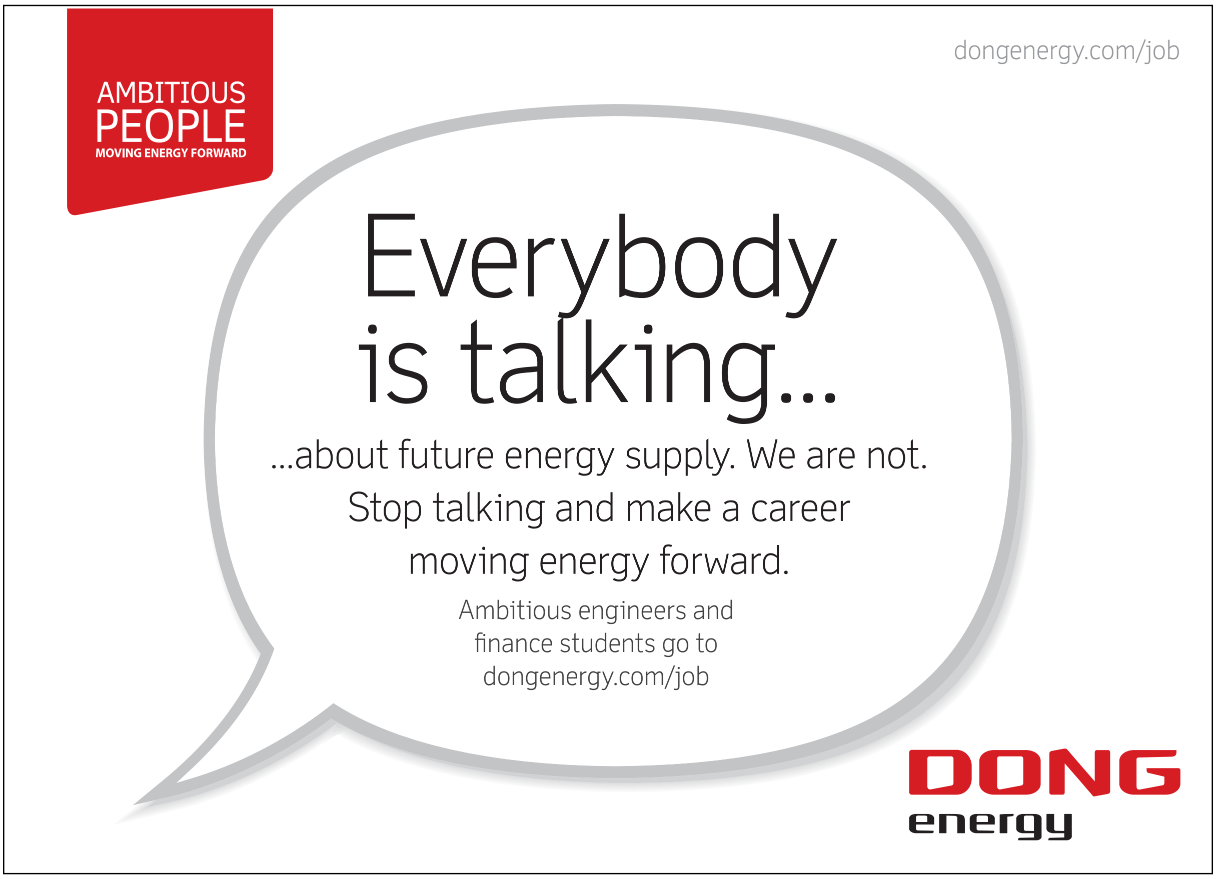
9.6 Air Quality Modelling and Forecasting

Air quality is modelled by air dispersion models (also called atmospheric diffusion model, air quality model, or air pollution dispersion model). A set of mathematical equations describing physical and chemical processes of air and its pollutants is solved by numerical methods on modern computers. The dispersion model is used to estimate or predict the downwind concentration of air pollutants emitted from various sources. Air dispersion models can be used by government agencies to determine whether an existing or new industrial plant will be in compliance with the relevant air quality standards. They are also used by public safety organisations for air quality forecasting (or scenario setting), which is important especially for emergency planning and operation of accidental chemical releases (e.g., evacuation or sheltering for persons in the downwind direction).

A typical air dispersion model requires information on 1) meteorological conditions: wind speed and direction, atmospheric turbulence, ambient air temperature, the height to the bottom of any inversion aloft that may be present, cloud cover and solar radiation; 2) pollutant source: the concentration or quantity of pollutants in emission or accidental release, temperature of the material, source location and height, type of source; 3) terrain: elevations at the source location and at the receptor location(s), land use/land cover information.

Dispersion models vary depending on the mathematics used to develop the model and a long list of those models can be found at Wikipedia 'list_of_atmospheric_dispersion_models'. In the UK and Europe, air quality forecast is carried out by coupling a numerical weather model and an air quality model (Defra, 2012). The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs (WRF, 2012). WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometres. For air quality forecasting across the UK and EUROPE WRF is initiated using NCEP Global Forecasting System (GFS) real-time data updated every 3 hrs. It is then run to provide 48-hour forecasts at 50km resolution for Europe and 10km resolution across the UK. The WRF model outputs are used as inputs to the CMAQ air quality forecasting model, and presented as a series of animated maps which the forecasting team use to review the expected weather situation. The Community Multi-scale Air Quality (CMAQ) modelling system has been designed to approach air quality as a whole by including state-of-the-science capabilities for modelling multiple air quality issues, including tropospheric ozone, fine particles, air toxics, acid deposition, and visibility degradation. An example of air quality forecast map is shown in Figure 9.5.

WRF also has its own air quality model called WRF-CHEM (WRF-CHEM, 2012), which is the WRF model coupled with Chemistry. The model simulates the emission, transport, mixing, and chemical transformation of trace gases and aerosols simultaneously with the meteorology. The model is used for investigation of regional-scale air quality, field program analysis, and cloud-scale interactions between clouds and chemistry.



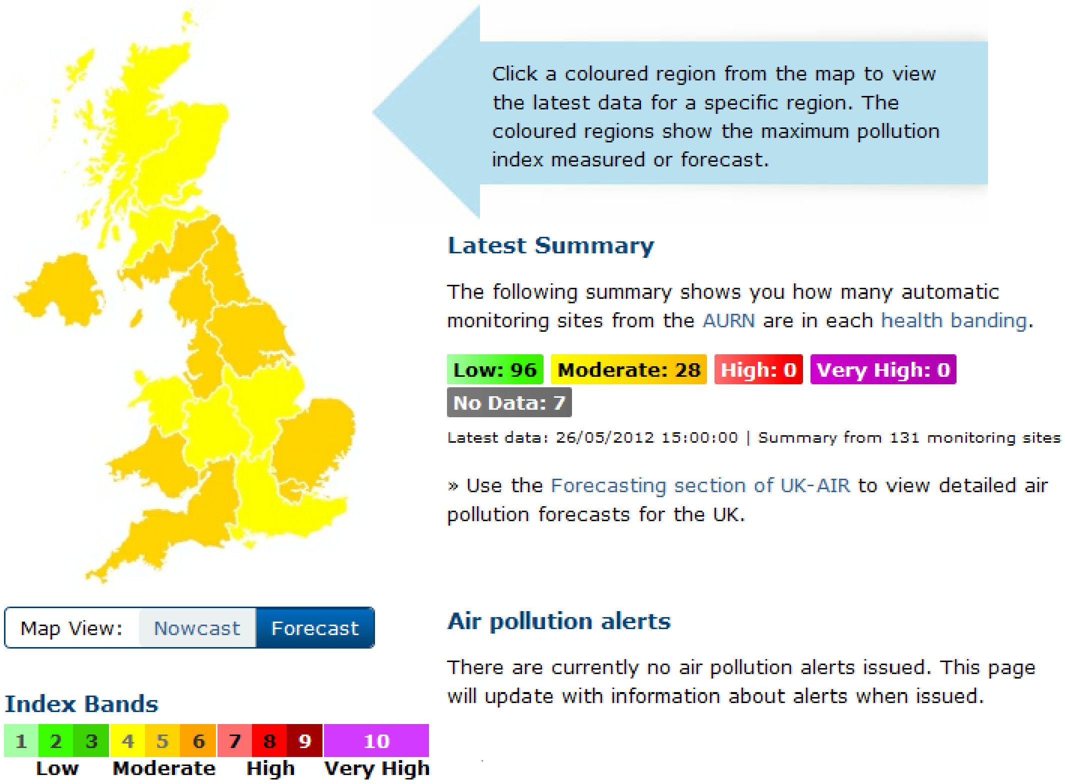


Figure 9.5 UK air pollution forecast map
(http://uk-air.defra.gov.uk/latest/?type=forecast)

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10 Noise Pollution

Noise is defined as unwanted sound in environmental engineering. This is in contrast to noise definitions in other fields where noise usually means unwanted information or data that is not relevant to the hypothesis or theory being investigated. For example, in telecommunication, noise is the unwanted random addition to a signal. In relation to sound, noise is not necessarily random (e.g., loud music from neighbours). Noise's effects include moderate annoyance to permanent hearing loss and may be rated differently by different observers. Nowadays, noise is pervasive and is almost impossible to escape from it. It is important for environmental engineers to understand noise so that its effect could be mitigated at design and operation of various buildings and machines.

10.1 Sources of Noise

Noise can be from a point source (e.g., a loudspeaker), a line source (e.g., power line under strong wind) or an area source (e.g., wind noise from a forest). They include sources from road traffic, aircraft, industrial plant, construction activities, sport and crowd activities, loud music from neighbours, etc. Poor urban planning may give rise to noise pollution, since side-by-side industrial and residential buildings can result in noise pollution in the residential area. Inadequate sound proof of buildings also contributes to noise problems.

In time, noise sounds can be classified as 1) continuous: an uninterrupted sound during the period of observation; 2) intermittent: a continuous sound with interruptive gaps, such as dentist drill; 3) impulsive: a sound of short duration, usually less than a second, such as gunfire.

In contrast to water and air pollutions, noise pollution has some unique characteristics: 1) the unwanted sound can be subjective so it may mean the wrong sound in the wrong place at the wrong time. Therefore, any sound could be noise; 2) noise pollution is usually local. Sound intensity follows an inverse square law with distance from the source; doubling the distance from a noise source reduces its intensity by a factor of four; and 3) there is no residual pollution after the noise source is removed.

10.2 Physical Properties of Noise

The 'noise' sound is a wave described by: wavelength (l), frequency (*f*) and speed (c) which are related by

$$c = \lambda f \tag{10.1}$$

The speed of sound in air at sea level at 20°C is about 340m/s. It travels faster in water (about 1500m/s) and solids (e.g., 5000m/s in iron). The human hearing frequency range is from 20 to 20,000 Hz.

Sound is a compression wave and it causes pressure changes in the air. Sound pressure (also called acoustic pressure) is the local pressure deviation from the ambient atmospheric pressure caused by a sound wave. Sound pressure can be measured using a microphone in air and hydrophone in water. The SI unit for sound pressure is Pascal (Pa). The effective sound pressure is the root mean square of the instantaneous sound pressure over a given interval of time as expressed in Eq (10.2)

$$P = \sqrt{\int_0^T p^2(t)dt / T} \qquad (10.2)$$

There is a huge range of audible sound pressures and in practice, it is more useful to convert sound pressure values (in Pa) to sound pressure level (SPL) which is a logarithmic measure of the effective sound pressure relative to a reference value. Since the sound power is proportional to the square of the sound pressure, the sound pressure level in decibels is defined as

$$L_P = 10\log_{10}\frac{P^2}{P_o^2} = 20\log_{10}\frac{P}{P_0} \quad \text{(dB)} \qquad (10.3)$$

where the reference sound pressure is $P_0 = 2\times10^{-5}$ (Pa) which is usually considered the threshold of human hearing (at 1 kHz). The decibel (dB) is used in a wide range of measurements in science and engineering. A change of the value ratio by a factor of 10 is a 10dB change and a change by a factor of 2 is approximately a 3dB change. The name decibel is linked with the Bell Telephone Lab who initiated this unit.

The formula for the sum of the sound pressure levels of several incoherent radiating sources is

$$L_{\Sigma} = 10\log_{10}\left(\frac{P_1^2 + P_2^2 + \ldots P_n^2}{P_o}\right) = 10\log_{10}\left(10^{L_{P1}/10} + 10^{L_{P2}/10} + \ldots + 10^{L_{Pn}/10}\right) \text{ (dB)} \quad (10.4)$$

The typical sound pressure levels are listed in Table 10.1.

Table 10.1 Examples of sound pressure levels
(Source : http://en.wikipedia.org/wiki/Sound_pressure)

Sound in air	Sound pressure level (dB)
Auditory threshold at 1kHz	0
Calm breathing	10
Very calm room	20-30
Normal conversation at 1m	40-60
TV at 1m	60
EPA noise limit	70
Passenger car at 10m	60-80
Threshold of pain	130

10.3 Human Perception of Noise

Human ears respond differently to different frequencies. Human voice contains frequency between 80 to 8000 Hz, but is mainly in 500 to 2000 Hz. In practice, sounds with a frequency above 8000 Hz are usually ignored in environmental noise monitoring because they are rarely encountered. For noise analysis, the whole audible frequency range is divided into a set of frequencies called bands. Each band covers a specific range of frequencies. An octave band is the frequency interval between a given frequency and twice that frequency: 1) 0.022-0.044 kHz; 2) 0.044-0.088 kHz; 3) 0.088-0.176 kHz; 4) 0.176-0.353 kHz; 5) 0.353-0.707 kHz; 6) 0.707-1.414 kHz; 7) 1.141-2.825 kHz; 8) 2.825-5.650 kHz; 9) 5.650-11.300 kHz; 10) 11.300-22.500 kHz.

Within the audible frequency range, the human ear is most sensitive between 2 and 5 kHz, largely due to the resonance of the ear system. An equal-loudness contour is a measure of sound pressure level, over the frequency spectrum, for which a listener perceives a constant loudness when presented with pure steady tones. The unit of measurement for loudness levels is phon, and is arrived at by reference to equal-loudness contours (Figure 10.1). By definition, two sine waves of differing frequencies are said to have the equal-loudness level measured in phons if they are perceived as equally loud by the average young person without significant hearing impairment. The value of phon is indicated by the sound pressure levels at 1000 Hz. From this figure, it can be seen that 92 dB at 100 Hz, 80 dB at 1000 Hz and 77 dB at 2000 Hz are perceived of the same loudness (i.e., 80 phons) by human ears. The measurement for those curves is subjective and different researchers may produce different curves. The blue line in Figure 10.1 is an updated curve set in 2003's international standard ISO 226:2003.

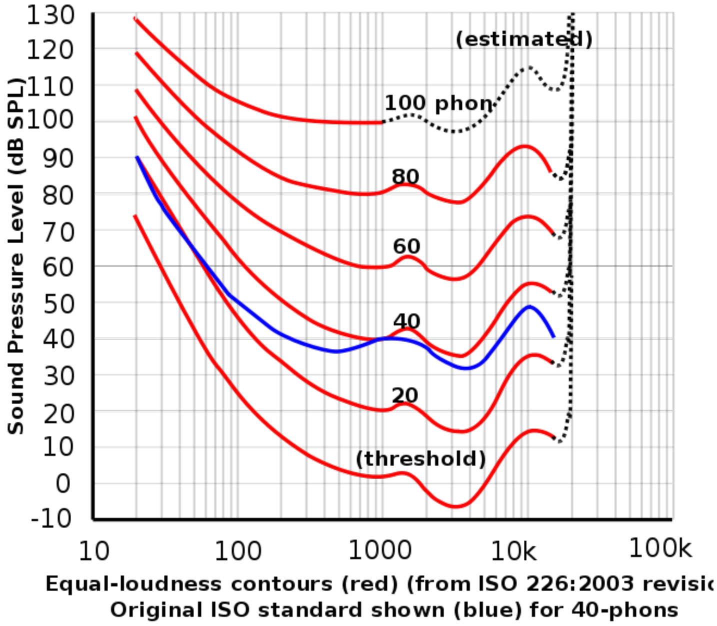

Figure 10.1 Equal loudness contour
(http://en.wikipedia.org/wiki/Equal-loudness_contour)

10.4 Noise Measurement

Noise is measured by sound level meters. Microphone is one of the key components in a sound level meter system. During measurements, it should be protected from mechanical damage, moisture and turbulence noise from wind. A special windshield and rain cover fitted to the microphone should be used if possible. Sound level meters should be calibrated by a pistonphone or a sound level calibrator both before and after its use. When measuring the noise level of a specific point source, the distance should always be stated. A distance of one metre from the source is commonly used. If the distance of the microphone to a sound source is omitted when measurements are quoted, it would make the data useless. In the case of ambient environmental measurements of "background" noise, distance needs not be quoted as no single source is present.

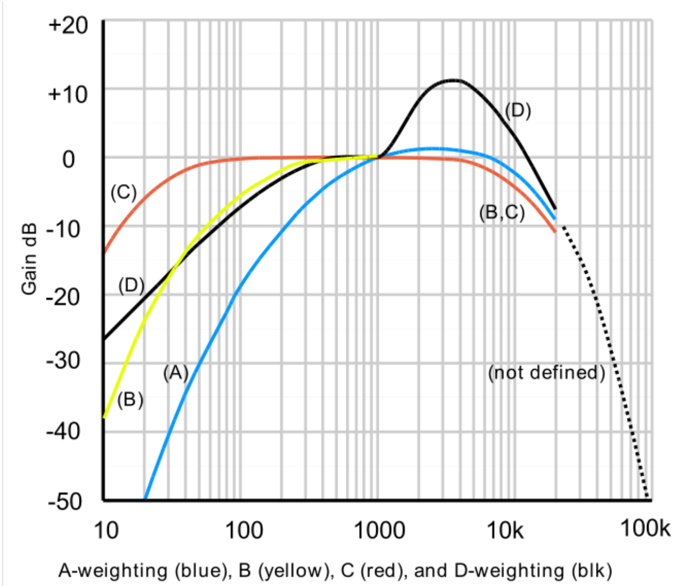

Figure 10.2 Weighting curves (Wikipedia 'A-weighting')

From the equal-loudness contours as shown in Figure 10.1, it is clear that two sounds with the same sound pressure level will be heard as different loudness levels at different frequencies. Therefore, sounds at different frequencies should be rated differently. To compensate for the frequency dependent sensitivity of human ears, sound level meters use a weight curve to combine sounds at different frequencies (Figure 10.2).

The curves are originally defined for use at different average sound levels. In order to distinguish the different sound measures, a suffix is used: A-weighted sound pressure level is written either as dB_A or L_A and B-weighted sound pressure level is written either as dB_B or L_B, etc. The A-weighting, though originally intended only for the measurement of low-level sounds (around 40 phons), is now commonly used for the measurement of environmental noise and industrial noise. The weighting is employed by arithmetically adding a table of values, listed by octave or third-octave bands, to the measured sound pressure levels in dB. The resulting octave band measurements are usually added (logarithmic method) to provide a single A-weighted value describing the sound.

10.5 Health Effects

Noise can damage human's physiological and psychological health, causing annoyance and aggression, hypertension, high stress levels, tinnitus, hearing loss, sleep disturbances, and other harmful effects. Chronic exposure to noise may cause noise-induced hearing loss.

In animals, noise can have a detrimental effect on their behaviours, increasing the risk of death by changing the delicate balance in predator or prey detection and avoidance, and interfering the use of the sounds in communication especially in relation to reproduction and in navigation. Noise pollution has caused the death of certain species of whales that beached themselves after being exposed to the loud sound of military sonar.

10.6 Noise Control

There are three elements to consider in noise control: Source -> Transmission path -> Receiver. 1) Source: the noise generation could be stopped or limited to certain times of the day; 2) Transmission path: this could be modified by putting the source inside a sound proof enclosure, constructing a noise barrier or using sound absorbing materials along the path; 3) Receiver: wearing ear protection or altering work schedule.

Generally, to reduce noise pollution, a set of strategies are needed to include transportation noise control, architectural design, and occupational noise control. For noise from roadways, highway noise is little affected by automobile type, since those effects are aerodynamic and tyre noise related. The most effective areas for roadway noise mitigation include urban planning, roadway design, noise barrier, speed control, surface pavement and truck restrictions. Speed control is effective since the lowest sound emissions arise from vehicles moving smoothly at 30 to 60 kilometres per hour. Above that range, sound emissions double with each five miles per hour of speed. At the lowest speeds, braking and (engine) acceleration noise dominates. Selection of surface pavement can make a difference of a factor of two in sound levels. Quieter pavements are porous with a negative surface texture and use medium to small aggregates. Noise barriers can be applicable for existing or planned surface transportation projects. They are probably the single most effective weapon in retrofitting an existing roadway, and commonly can reduce adjacent land use sound levels by up to ten decibels (Figure 10.3).

Figure 10.3 Noise barrier along M1 in London, England (Google Street View)

Because of its velocity and volume, the noise from jet turbine engine exhausts defies reduction by any simple means. The most promising forms of aircraft noise abatement are through land planning, flight operations restrictions and residential soundproofing. Flight restrictions can take the form of preferred runway use, departure flight path and slope, and time-of-day restrictions.

To design quieter buildings, many countries have stringent building codes with requirements of acoustical analysis, in order to protect building occupants. With regard to exterior noise, the codes usually require measurement of the exterior acoustic environment in order to determine the performance standard required for exterior building skin design. The most important elements in designing a building skin are usually: glazing (glass thickness, double pane design etc.), roof material, caulking standards, chimney baffles, exterior door design, etc. Regarding sound generated inside the building, there are two principal types of transmission. Firstly, airborne sound travels through walls or floor and ceiling assemblies, which emanates from either human activities in adjacent living spaces or from mechanical noise within the building systems. Human activities might include voice, amplified sound systems or animal noise. Mechanical systems are elevator systems, boilers, refrigeration or air conditioning systems. Since many of these sounds are inherently loud, the principal design element is to require the wall or ceiling assembly to meet certain performance standards, which allows considerable attenuation of the sound level reaching occupants. The second type of interior sound arises from transmission of sound through the building itself, such as from footfall of occupants in living spaces above. This type of noise is more difficult to abate, but consideration must be given to isolating the floor assembly above or hanging the lower ceiling on resilient channel.

Industrial noise is usually considered mainly for environmental health and safety, rather than nuisance, as sustained exposure can cause permanent hearing damage. This situation usually involves primarily manufacturing settings where industrial machinery produces intense sound levels. While this circumstance is the most dramatic, there are many other office type environments where sound levels may lie in the range of 70 to 75 decibels, entirely composed of office equipment, music, public address systems, and even exterior noise intrusion. The latter environments can also produce noise health effects if exposures are long term. In the case of industrial equipment, the most common techniques for noise protection of workers consist of shock mounting source equipment, creation of acrylic glass or other solid barriers, and provision of ear protection equipment. In certain cases the machinery itself can be re-designed to operate in a manner less prone to produce grating, grinding, frictional or other motions that induce sound emissions.

Further reading materials

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11 Climate Change - Impact, Mitigation and Adaptation

Climate is the statistics of long term (the standard period is 30 years) meteorological variables (e.g., temperature, humidity, atmospheric pressure, wind, and others). The statistics include average, variance, skewness, and others. The climate of a location is affected by its land use/land cover, latitude, terrain, altitude, etc. Climate change has great implications for future environmental risk assessment and sustainability. It is important for environmental engineers to understand how climate could be altered by human actions either intentionally or inadvertently, and what mitigation and adaptation approaches should be adopted.

11.1 Climate Observation

Details of the modern climate records are known through the taking of measurements from weather instruments such as thermometers, barometers, and anemometers during the past few centuries. Figure 11.1 shows the instrumental global surface temperature record since the late 19th century due to the widespread reliable measurements. Satellites may also be used to retrieve surface temperatures in cloud-free conditions, generally via measurement of thermal infrared images. Weather satellites have been available to infer sea surface temperature (SST) information since 1967, with the first global composites made during 1970.

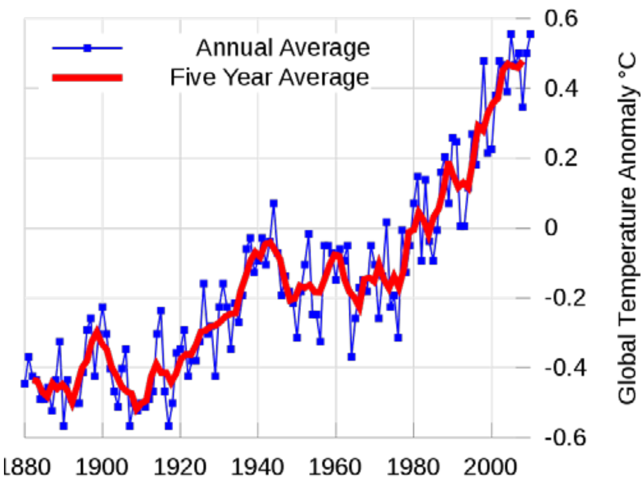


Figure 11.1 Instrumental temperature record (Wikipedia 'Instrumental temperature record')

Paleoclimatology is the study of past climate over a great period of the Earth's history. It uses evidence from ice sheets, tree rings, sediments, coral, and rocks to determine the past climate. The reconstructed past climate demonstrates the variations of climate in different periods of the Earth history (Figure 11.2).

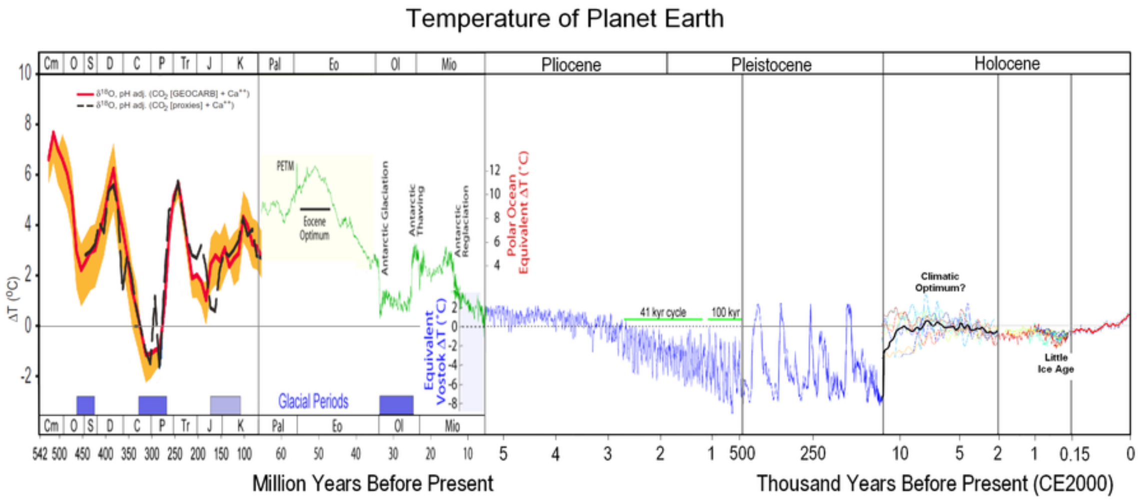


Figure 11.2 Reconstructed past climate (Wikipedia 'Paleoclimatology')

11.2 Climate Change Mechanisms

At the planetary scale, the global climate is regulated by how much energy the Earth receives from the Sun. However, the global climate is also affected by other flows of energy which take place within the climate system itself. This global climate system is made up of the atmosphere, the oceans, the ice sheets (cryosphere), living organisms (biosphere) and the soils, sediments and rocks (geosphere), which all affect, to a greater or less extent, the movement of heat around the Earth's surface.

Research has shown that human activity can have significant impacts on weather and climate over a broad range of space and timescales. The question is whether the human disturbance of the regional and global climate can be extracted from the large natural variability that occurs on these scales. The main and imminent effect of human on the global climate system, as it impacts society, is not from a globally averaged increase in surface temperature. The more important effect is if humans have altered atmospheric and ocean circulation patterns, such as the position of the polar jet stream, and how the troughs and ridges of pressure are established, and if ocean conveyor belts are modified. Pielke et al. (2002) and Feddema et al. (2005) illustrated how land-use change could accomplish large circulation change, but without a change in the globally averaged surface temperature.

11.2.1 Climate Forcing

A climate forcing is defined as 'an energy imbalance imposed on the climate system either externally or by human activities' (National Research Council, 2005). The principal source of energy driving the atmospheric/ocean system comes from the Sun. The Sun emits most of its radiant energy over wavelengths ranging from 0.2 to 1.8 mm, with a peak intensity at 0.47mm. On the other hand, the spectrum of energy emitted by the Earth is most around 6 – 25 mm. The energy emitted by the Sun is shortwave radiation and the energy emitted by the Earth and its atmosphere is longwave radiation. There is very little overlap between them in spectrum.

The solar energy is significantly attenuated by the time it reaches the Earth's surface at sea level. It is not attenuated uniformly across the spectrum, but instead major energy losses occur over rather narrow bands, called absorption bands. In a cloud-free clean atmosphere, the primary absorbers of shortwave radiation are **water vapour and ozone**. Airborne particles, or aerosols, in typical non-polluted air contribute less to absorption. Absorption of longwave radiation occurs in a series of bands. The principal natural absorbers of longwave radiation are water vapour and carbon dioxide (and some minor players such as ozone, methane, CFC and nitrous oxide which are much less influential). They are the principal '**greenhouse' gases**. The basic greenhouse concept was proposed by Fourier (1827). Later, Arrhenius (1896) calculated the effects of varying carbon dioxide concentrations on surface temperature and even included the impact of water vapour absorption in his calculations (Cotton and Pielke, 2007, pp155). The most important greenhouse gas is water vapour which varies naturally in space and time due to the Earth's hydrological cycle. The 2nd most important greenhouse gas is carbon dioxide. In contrast to water vapour, carbon dioxide is rather uniformly distributed throughout the troposphere.

The radiative properties of **aerosol particles** are a complicated function of their chemistry, shape, and size spectra. Moreover, if the aerosol particles are hygroscopic, their radiative properties change with the relative humidity of the air. Dry aerosol particle in high concentrations such as over major polluted urban areas and over deserts can cause substantial absorption and scattering of solar radiation.

Like aerosol particles, **cloud droplets, rain drops**, and **ice particles** interact with radiation in complex ways. Numerous small, liquid cloud droplets are strong reflectors of solar radiation, while raindrops, though much fewer in number, are strong absorbers of solar radiation, but are small contributors to scattering. Likewise, numerous small ice crystals can be strong reflectors of solar radiation while being weak absorbers. Except for very deep, wet clouds, absorption of solar radiation by cloud droplets and ice crystals is small. By contrast, absorption of longwave radiation by clouds is quite large, while they reflect longwave radiating rather poorly.

The climate of the Earth will remain constant as long as the apportionment of energy contributions to the global budget remains the same. A systematic change in one or more components can lead to a radiative imbalance in the global budget and lead to warming or cooling of globally averaged heat content. If all existing greenhouse gases were removed from the atmosphere, the amount of longwave energy emitted to space would be greatly enhanced. This would result in an average surface temperature of the Earth about 30°C cooler than it is today (Pielke, 2003).

The **total energy output from the Sun** cannot be viewed as being a constant. There is evidence suggesting that early in the Earth's history, the Sun's output was 25% less than it is today. In recent history, solar luminosity has been observed to decline from 1980 to 1986 and to increase since 1986. Solar luminosity is positively correlated to sunspot number with 11-year cycle with an amplitude change of $0.1 Wm^{-2}$ at the top of the atmosphere. The geometry of the Earth's orbit around the Sun also changes with time. There is a 41,000-year oscillation in the Earth's tilt and a 22,000-year precession cycle. The Milankovitch theory predicts that the Earth will gradually be moving into an ice age over the next 5000 years. It remains to be seen if the impact of anthropogenic activities on climate can alter the effect of the orbital forcing on climate trends.

Volcanoes are the major source of natural aerosol particles which can significantly attenuate solar radiation. A major volcanic eruption such as Tambora in 1815 and Pinatubo in 1991 can spew large quantities of aerosols and gases into the lower stratosphere where they can reside for months to several years. The high-level aerosol particles reflect some of the incoming radiation, thus increasing planetary albedo, and absorb solar radiation in the stratosphere, thus reducing the amount of energy reaching the Earth's surface. Therefore, a single large volcanic eruption can reduce surface temperatures by several tenths of a degree for several years (Hansen et al., 1988). Because large volcanic eruptions cannot be predicted, they represent a major source of uncertainty in predicting climate trends. A collision between the Earth and a large meteor or comet is another potentially major source of dust and aerosol. Since the frequency of such events is so low, they are generally thought to be a minor factor in climate change over the next several hundred years.

The **surface properties** have an important role in the Earth's radiation balance. The albedo of the surface of the Earth is determined by the percent coverage of ocean versus land, the amount of glacial coverage, and properties of the land surface such as the amount of desert versus forested lands. Dust ejected into the atmosphere by wind from deserts also results in a major influence on the radiative balance.

11.2.2 Climate Feedback

Climate feedback is amplification or dampening of the climate response to a specific forcing due to changes in the atmosphere, oceans, land, or continental glaciers.

Water vapour is a principal greenhouse gas and any changes in water vapour concentration in response to greenhouse gases would substantially alter the net greenhouse heating. As the atmosphere and ocean warm in response to enhanced greenhouse warming, more water vapour evaporates from the ocean and land surfaces. The higher water vapour content of the atmosphere causes further greenhouse warming, which then causes more evaporation (positive feedback).

There are other possible feedbacks associated with higher moisture contents, which complicate this feedback process. **Clouds** can lead to both warming and cooling of the atmosphere through their interactions with radiation. Simulation of the moisture feedback in climate models requires realistic models of hydrological budget (rainfall, physical evaporation and transpiration of water vapour from land and ocean surfaces) and of the response of the ocean to heating of the atmosphere. Unfortunately, the responses of the various climate models to simulated surface energy budge are diverse.

Changes in surface snow and ice coverage respond positively to greenhouse warming. Snow and ice reflect more solar radiation than open water, bare soil, or soil covered by vegetation. As a result, a warming high latitude troposphere is expected to reduce sea ice cover accordingly, and to cause earlier seasonal melting of snow and a retreat in glaciers. It is estimated that these effects would positively amplify greenhouse warming by 10% to 20% globally (Hansen, 1986). The ice albedo and snow albedo feedbacks are difficult to model accurately and the existing climate models failed to predict and match the observed sea ice coverage changes in the polar regions.

An even more complicated feedback in surface albedo and surface fluxes is associated with changes in **vegetation coverage**. If the tundra-boreal forest boundary should shift poleward in response to a warming planet, this would cause a decrease in albedo and represent a positive feedback. If, on the other hand, desert increases in semi-topical areas due to reductions in rainfall, this could create a negative effect. Likewise, it is possible that enhanced carbon dioxide concentration will serve as a fertiliser and result in increased biomass coverage causing a decrease in albedo and positive feedback. The increase of biomass, however, would provide an enhanced atmospheric sink of carbon, at least until new biomass decays (Cotton and Pielke, 2007).

Ocean is able to store a large amount of heat. As a result, the time that it takes the atmosphere-ocean system to respond to greenhouse warming is largely controlled by the ocean response. If exchanges of heat with the deep ocean are small, the upper mixed layer of the ocean, which is commonly about 7 to 100m deep, will respond to a warming atmosphere on the timescale of decades. If, on the other hand, the rate of exchange of heat with deep ocean layers, it may require time scales on the order of a century or more for the upper levels of the ocean to respond appreciably to greenhouse warming. Ocean is also a large reservoir of carbon dioxide. The ocean contains as much as 50 times the amount of carbon as resides in the atmosphere. The simplest feedback is that as the ocean warms, the solubility of the carbon dioxide decreases and more carbon dioxide is released from the ocean to the atmosphere creating a positive feedback. However, cold, upwelling regions of the ocean (which require high spatial resolution models to simulate) may provide a region for carbon sinks from the atmosphere even if the ocean surface were to warm overall (Pielke, 1991).

11.3 Modelling of Climate Change

Despite the difficulty and uncertainty with climate modelling, many research organisations have developed climate models to help the assessment of different forcing and feedback components. There is still a long way to go before these models could provide accurate forecasts. Climate models use quantitative methods to simulate the interactions of the atmosphere, oceans, land surface, and ice. They are used for a variety of purposes from study of the dynamics of the climate system to projections of future climate. The most talked-about use of climate models in recent years has been to project temperature changes resulting from increases in atmospheric concentrations of greenhouse gases. All climate models take account of incoming energy from the Sun as short wave electromagnetic radiation, chiefly visible and short-wave (near) infrared, as well as outgoing energy as long wave (far) infrared electromagnetic radiation from the Earth. Any imbalance results in a change in temperature.

GCMs (global climate models or general circulation models) discretise the equations for fluid motion and energy transfer and integrate these over time. However, they are still under development and uncertainties remain (Figure 11.3). They may be coupled with the models of other processes, such as the carbon cycle, so as to better model feedback effects. Most recent simulations show "plausible" agreement with the measured temperature anomalies over the past 150 years when forced by natural forcings alone, but better agreement is achieved when observed changes in greenhouse gases and aerosols are also included.

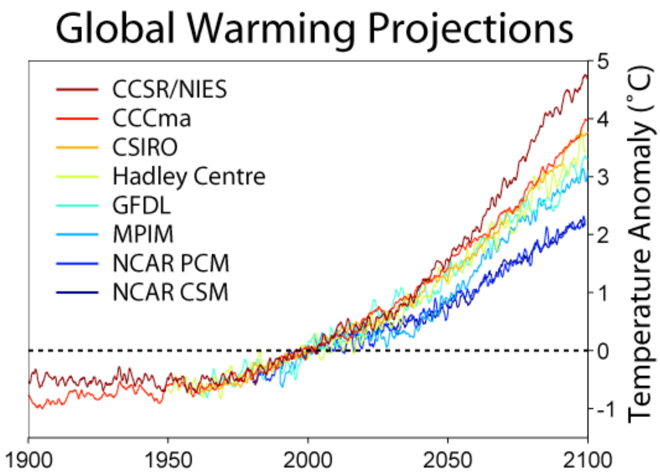


Figure 11.3 IPCC graphic of uncertainty ranges with various models over time (Wikipedia 'Climateprediction.net')

11.4 Importance of Natural Variability

Ice cores have shown that a switch from an ice age climate to a non-ice age environment can occur over only a few decades (La Brecque, 1989). No climate model has been able to predict or even adequately explain these rapid transitions. Short term variations of weather and climate are clearly within the natural variability of climate to the extent that we can realistically assess it. Moreover, the models are not really 'forecast' models (Pielke, 2002). They are simply research models designed to simulate the responses of hypothesised anthropogenic changes to weather and climate, other things being the same. These model simulations should more appropriately be referred to as process studies, not predictions. With their many limitations in their description of climate forcing and feedbacks, they are not capable of predicting climatic change with a high confidence. We simply do not know enough about all the processes of importance to climate change to include them in any quantitative forecasting system (National Research Council, 2005). Many people are grossly underestimating the complexity of interactions among the Earth's atmosphere, ocean, geosphere, and biosphere, and overstating the accuracy of the climate models to predict the future climates. These problems are so complex that it may take many decades, or even centuries, before we have matured enough as a scientific community to make credible predictions of long term climate trends and their corresponding impacts (Cotton and Pielke, 2007). Widmann and Tett (2003) conclude that 'even a perfect model with all forcing included will simulate only one of many possible climate scenarios consistent with the forcing'. Volcanic eruptions and influences outside of the Earth could be so large to render the forecasts unusable.

11.5 Impact

The impacts of climate change are reflected in the changes in various aspects of concern to human beings and ecosystems. On the physical world, climate change triggers changes in global and regional weather. Generally, projections of future climate changes at the regional scale do not hold as a high level of scientific confidence as projections made at the global scale. The temperature changes are more visible over land and the polar regions than oceans, and more in high latitude regions than low latitude ones. Precipitation over the globe is expected to increase, but with substantial shifts in where and how precipitation falls, intensity, frequency, and types (with decreasing precipitation in some areas). Also, increased extremes of summer dryness and winter wetness are projected for much of the globe, meaning a generally greater risk of droughts and floods. There are widespread melting of snow and ice with visible decrease in glaciers (reductions in glacier extent and thickness) and ice caps, and rising global average sea level. For volcanoes and earthquakes, the retreat of glaciers and ice caps can cause increased volcanism and seismicity due to reduced confining pressure exerted on the Earth crust. The oceans serve as a sink for carbon dioxide and increased levels of CO_2 have led to ocean acidification, albeit this is alleviated to a certain degree by the ocean temperature increase with a less ability to absorb excess CO_2 (The amount of oxygen dissolved in the oceans would decline as well due to increased temperature). Oceans are expected to have increased temperature stratification and large-scale changes in ocean circulation.

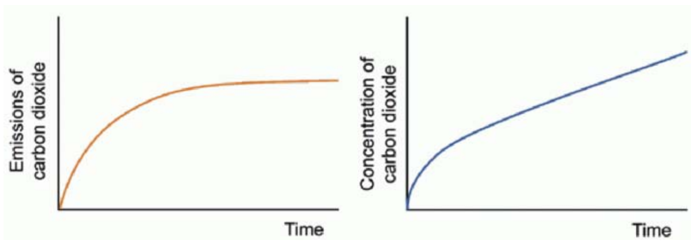
On the social world, the sensitivity of human society to climate change varies. Sectors sensitive to climate change include water resources, coastal zones, human settlements, and human health. Industries sensitive to climate change include agriculture, fisheries, forestry, energy, construction, insurance, financial services, tourism, and recreation. Generally, adverse impacts of climate change are expected to fall disproportionately upon developing countries. In agriculture, crop yields are affected due to the effects of elevated CO_2 in the atmosphere, higher temperatures, altered precipitation and transpiration regimes, increased frequency of extreme events, and modified weed, pest, and pathogen pressure, with low-latitude areas at most risk (while on the other hand, productivity may increase in high latitudes with moderate temperature increase). More studies are needed to consider the effects of changes in extreme events, the spread of pests and diseases. The effect of climate change on human health is reflected by exposure through changing weather patterns (temperature, precipitation, sea-level rise and more frequent extreme events) and indirectly through changes in water, air and food quality and changes in ecosystems, agriculture, industry, settlements and the economy. On the other hand, climate change would bring some benefits in temperate areas, such as fewer deaths from cold exposure, and some mixed effects such as changes in range and transmission potential of malaria in Africa. On extreme events, climate change is expected to increase the number of people suffering from death, disease and injury from heatwaves, floods, storms, fires and droughts. On water resources, impacts of climate change on freshwater systems and their management are mainly due to changes in temperature, sea level and precipitation variability. Sea level rise will extend areas of salinisation of groundwater and estuaries, resulting in a decrease in freshwater availability for humans and ecosystems in coastal areas. More than one-sixth of the world's population are supplied by meltwater from major mountain ranges. Changes in glaciers and snow cover are expected to reduce water availability for these populations.

On the biological world, impacts of climate change include earlier leafing of trees and plants over many regions, movements of species to higher latitudes and altitudes in search of cooler temperatures, changes in bird migrations, and shifting of the oceans' plankton and fish from cold to warm adapted communities. The amount of oxygen dissolved in the oceans may decline, with adverse consequences for ocean life. Ocean acidification on the marine biosphere may have some beneficial effects for a few species, with potentially highly detrimental effects for a substantial number of species. The stresses caused by climate change, added to other stresses on ecological systems (e.g., land conversion, land degradation, harvesting, and pollution), may cause substantial damage to some unique ecosystems, and extinction of some critically endangered species. Climate change has been estimated to be a major driver of biodiversity loss in cool conifer forests, savannas, Mediterranean-climate systems, tropical forests, the Arctic tundra, and coral reefs.

Physical, ecological and social systems may respond in an abrupt, non-linear or irregular way to climate change, as opposed to a smooth or regular response. Irregular behaviour in the Earth systems may give rise to certain thresholds (tipping points), which, when crossed, may lead to a large change in the system. Human-induced climate change may lead to irreversible impacts on physical, biological, and social systems (e.g., extinction of species, lost of unique human cultures due to displacement of communities by sea level rise). It is possible that human-induced climate change could trigger large-scale singularities, but the probabilities of triggering such events are still poorly understood.

11.6 Mitigation

Mitigation on climate change is a human intervention to reduce the potential effects of climate change by reducing the sources or enhancing the sinks of greenhouse gases. It should be noted that stabilising GHG emissions is not sufficient for stabilising GHG concentrations. This is only possible when GHG emissions are significantly reduced to the removal rate by natural processes (Figure 11.4). Mitigation examples include using fossil fuels more efficiently for industrial processes or electricity generation, switching to renewable energy (solar power, tidal and ocean energy, geothermal power, and wind power) and more controversially nuclear power, improving the insulation of buildings, and expanding forests and other "sinks" to remove greater amounts of carbon dioxide from the atmosphere, changing individual-lifestyles and business practices. The ever-increasing global population and the planned growth of national GDPs based on current technologies are counter-productive to most of these proposals.



(a) Stabilising CO_2 emission

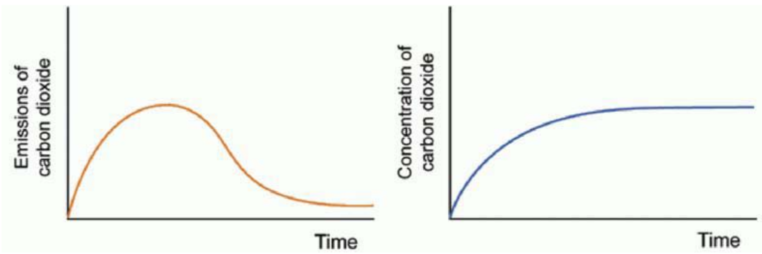


Figure 11.4 Stabilisation of CO_2 emission/concentration
(Wikipedia 'Climate change mitigation')

There are some emerging mitigating measures that could play important roles in the future. Carbon capture and storage (CCS) is a method to mitigate climate change by capturing carbon dioxide from large point sources such as power plants and subsequently storing it away safely (in deep geological formations, in deep ocean masses, or in the form of mineral carbonates) instead of releasing it into the atmosphere. However, capturing and compressing CO_2 may increase the fuel needs of a coal-fired CCS plant by 25%-40%. A general problem is that long term predictions about submarine or underground storage security are very difficult and uncertain, and there is still the risk that CO_2 might leak from the storage into the atmosphere.

Urban planning also has an effect on energy use by reducing sprawl to decrease Vehicle Miles Travelled (VMT), lowering emissions from transportation. Increased use of public transport can also reduce greenhouse gas emissions per passenger kilometer. Emissions from housing are substantial and government-supported energy efficiency programmes can make a difference. New buildings can be constructed using passive solar building design, low-energy building, or zero-energy building techniques using renewable heat sources. Existing buildings can be made more efficient through the use of insulation, high-efficiency appliances (particularly hot water heaters and furnaces), double- or triple-glazed gas-filled windows, external window shades, and building orientation and siting. Renewable heat sources such as shallow geothermal and passive solar energy reduce the amount of greenhouse gasses emitted.

Geoengineering refers to the deliberate large-scale engineering and manipulation of the planetary environment in order to counteract the effects of climate change. It mainly includes solar radiation management and carbon dioxide removal. Solar radiation management (SRM) projects seek to reduce the net incoming short-wave (ultra-violet and visible) solar radiation received, by deflecting sunlight, or by increasing the reflectivity (albedo) of the atmosphere. They do not reduce greenhouse gas concentrations in the atmosphere, and thus do not address problems such as ocean acidification caused by these gases. Solar radiation management projects often have the advantage of speed. On the other hand, carbon dioxide removal projects seek to remove greenhouse gases from the atmosphere (e.g., fertilising the world's oceans with iron), and thus tackle the root cause of global warming. They either directly remove greenhouse gases, or alternatively seek to influence natural processes to remove greenhouse gases indirectly. These projects offer a comprehensive solution to the problem of excess greenhouse gases in the atmosphere, but they will take many years to work fully. It is generally agreed that engineered countermeasures need to be evaluated but should not be implemented without broad understanding of the direct effects and the potential side effects, the ethical issues, and the risks. It is recognised that geoengineering technologies do not now offer a viable response to global climate change

11.7 Adaptation

Climate change adaptation is to take actions to cope with the effects of climate change. Adaption is necessary because climate change and its effects are unlikely to be mitigated within a short period. Adaptation will be more difficult for larger magnitudes and higher rates of climate change. Climate change adaptation is especially important in developing countries since those countries are predicted to bear the brunt of the climate change effects. Adaptive capacity is closely linked to social and economic development, and developing countries generally have less capacity to adapt.

Adaptation can be defined as adjustments of a system to reduce vulnerability and to increase the resilience of system to change. Adaptation occurs at a range of inter-linking scales, and can either occur in anticipation of change (anticipatory adaptation), or be a response to those changes (reactive adaptation). Most adaptation being implemented at present is responding to current climate trends and variability (e.g., increased use of artificial snow-making in the European Alps) and some adaptation measures, however, are anticipating future climate change (e.g., to design a bridge high enough with the expected water level rises).

Planning represents an important avenue for adaptation by allocating land use for ecosystem protections. In cities, it may be appropriate to change to heat tolerant tree varieties and water permeable pavements to absorb higher rainfalls. Sustainable drainage systems could help urban areas adapt to increasingly severe storms by increasing rainwater storage and increasing the capacity of storm water systems. Gardens may use plants which require less water and provide habitats for the most threatened species. For agriculture, it is important to develop crop varieties with greater drought tolerance and increase investment in irrigation (e.g., modern efficient irrigation systems, small-scale water storage ponds). Weather control techniques could be explored (e.g., cloud seeding) to try to produce rain when and where it is needed. Glacial lakes in danger of bursting can have their moraines replaced with concrete dams (which may also provide hydroelectric power). Migration could also be considered when other mitigation measures have proven unsuccessful.

Further reading materials

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