EARTH AND ITS POPULATION

The Earth

The planet on which we live is only one of nine planetary bodies that revolve around the Sun in the solar system. Earth is the third in distance from the sun and the fifth largest of the planets in diameter. The Earth is essentially a nearly spherical geoid or ellipsoid of rotation slightly flattened at the poles. Some of its characteristics are listed in Table 1 and below.

- Diameter varies between 12,713.54 km or 7,899.83 mi (polar diameter) and 12,756.34 km or 7,926.42 mi (equatorial diameter);
- Volume is about 1,083 billion km^3 or 259 billion mi^3;
- Mass is about 5.98 x 10^{21} metric tons;
- Total surface area is about 510 million km^2 or 197 million mi^2, 71% of which is covered with water;
- Average density is 5.52 g/cm^3 which is about twice that of its surface rocks;
- Highest point is Mount Everest at 29,000 ft (8.848 km), and its deepest point is the Mariana trench (near the Philippine Island of Mindanao) at -36,500 ft (-11.033 km);
- Highest temperature is 58° C (136° F) at Al Aziziyah, Libya and lowest is -89.6° C (-128.6° F) at Vostok Station, Antarctica. The average surface temperature is 14° C (57°F);
- Atmospheric components: 78% nitrogen, 21% oxygen and 1% argon.

Earth Statistics	
Mass (kg)	5.976e+24
Mass (Earth = 1)	1.0000e+00
Equatorial radius (km)	6,378.14
Equatorial radius (Earth = 1)	1.0000e+00
Mean density (gm/cm^3)	5.515
Mean distance from the Sun (km)	149,600,000
Mean distance from the Sun (Earth = 1)	1.0000
Rotational period (days)	0.99727
Rotational period (hours)	23.9345
Orbital period (days)	365.256
Mean orbital velocity (km/sec)	29.79
Orbital eccentricity	0.0167
Tilt of axis (degrees)	23.45
Orbital inclination (degrees)	0.000
Equatorial escape velocity (km/sec)	11.18
Equatorial surface gravity (m/sec^2)	9.78
Visual geometric albedo	0.37
Mean surface temperature	15°C
Atmospheric pressure (bars)	1.013
Atmospheric composition	
Nitrogen	77%
Oxygen	21%
Other	2%

Table 1 Earth Statistics (http://www.solarviews.com/eng/earth.htm).

Additional information about the Earth and other planets can be found in the following web pages or by consulting various encyclopedias:

http://earth.jsc.nasa.gov/
http://pds.jpl.nasa.gov/planets/welcome/earth.htm

The Earth consists of five parts: the atmosphere (gaseous), the hydrosphere (liquid), and three solid parts called the lithosphere, the mantle, and the core.

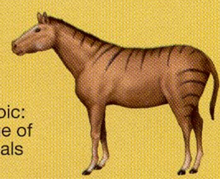
The oldest rocks on Earth have been dated to be 4 billion years old. Using radioactive dating of rocks, scientists have been able to construct an absolute chronology of geologic time. The *geologic time scale* shows that chronology (see Fig. 1). If the age of the Earth were reduced to a 24-hour scale, the human species would not appear until the last few seconds. We will talk about the geologic time scale later during the semester. For the time being, you should know that the Earth is old (but well alive) with an age of about 4.65 billion years (based on the age of meteorites that fell on Earth).

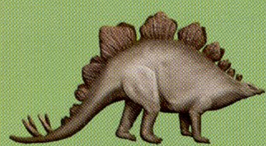
The behavior of earthquake waves has led geophysicists to conclude that the Earth is a density-stratified planet consisting of: (1) a dense *core* (inner and outer), (2) a *mantle* (inner and outer), (3) and the *crust*. An idealized picture of the Earth is shown in Fig. 2.

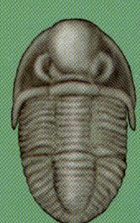
- The core is about 3,486 km (2,178 miles) in radius, and it is believed to consist of iron with a solid inner part and a liquid outer part. The density of the core ranges from 9.4 g/cm^3 at the outer limit to 13.7 g/cm^3 at the center of the core.

- The mantle is 2,885 km (1,803 miles) thick and is believed to consist of silicate rocks rich in iron, magnesium, aluminum, and calcium. The outer (or upper) mantle has a density that increases downward from 3 to 4.5 g/cm^3 whereas the inner mantle has a density increasing downward from 4.5 to 8 g/cm^3. The contact between the mantle and the core is called the *Wiechert-Gutenberg Discontinuity.*

- The crust varies in thickness and composition depending if it is associated with continents (continental crust) or oceans (oceanic crust). The contact between the crust and the upper mantle is called the *Mohorovicic Discontinuity* (or Moho). It lies 6-8 miles (10-13 km) below oceans and much deeper up to 44 miles (70 km) under deep-seated parts of continents (such as under large mountain ranges or belts). This variation of crust thickness is shown in Fig. 2. The continental crust, sometimes called *Sial* (because of its silicon-aluminum chemical content) is a granitic layer with a density of about 2.7 g/cm^3. This zone is underlain with a basaltic substratum also called *Sima* (for its silicon-magnesium chemical content) with a density of about 3 g/cm^3 (or 3 t/m^3). In the oceanic crust, the granitic zone is absent, and the basaltic substratum is dominant.







The Geologic Time Scale

Eon	Era	Period**	Epoch	Approximate Ages (In millions of years)
Phanerozoic: The Eon of Visible Life	Cenozoic: The Age of Mammals	Quaternary (Q)	Recent, Pleistocene (Neogene*)	1.6
		Tertiary (T)	Pliocene, Miocene (Neogene*); Oligocene, Eocene, Paleocene (Paleogene*)	24; 65
	Mesozoic: The Age of Reptiles	Cretaceous (K)	Late, Early	144
		Jurassic (J)	Late, Middle, Early	213
		Triassic (R)	Late, Middle, Early	248
	Paleozoic: The Age of Trilobites	Permian (P)	Late, Early	286
		Carboniferous (C)*: Pennsylvanian (IP)	Late, Middle, Early	320
		Carboniferous (C)*: Mississippian (M)	Late, Early	360
		Devonian (D)	Late, Middle, Early	417
		Silurian (S)	Late, Middle, Early	445
		Ordovician (O)	Late, Middle, Early	495
		Cambrian (€)	Late, Middle, Early	545
	Precambrian (PC)	Locally divided into Early, Middle, and Late		4500+

*European names

**Symbols in parentheses are abbreviations commonly used to designate the age of rock units on geologic maps.

Figure 1 Relative geologic time scale (after Anders et al., 1997)

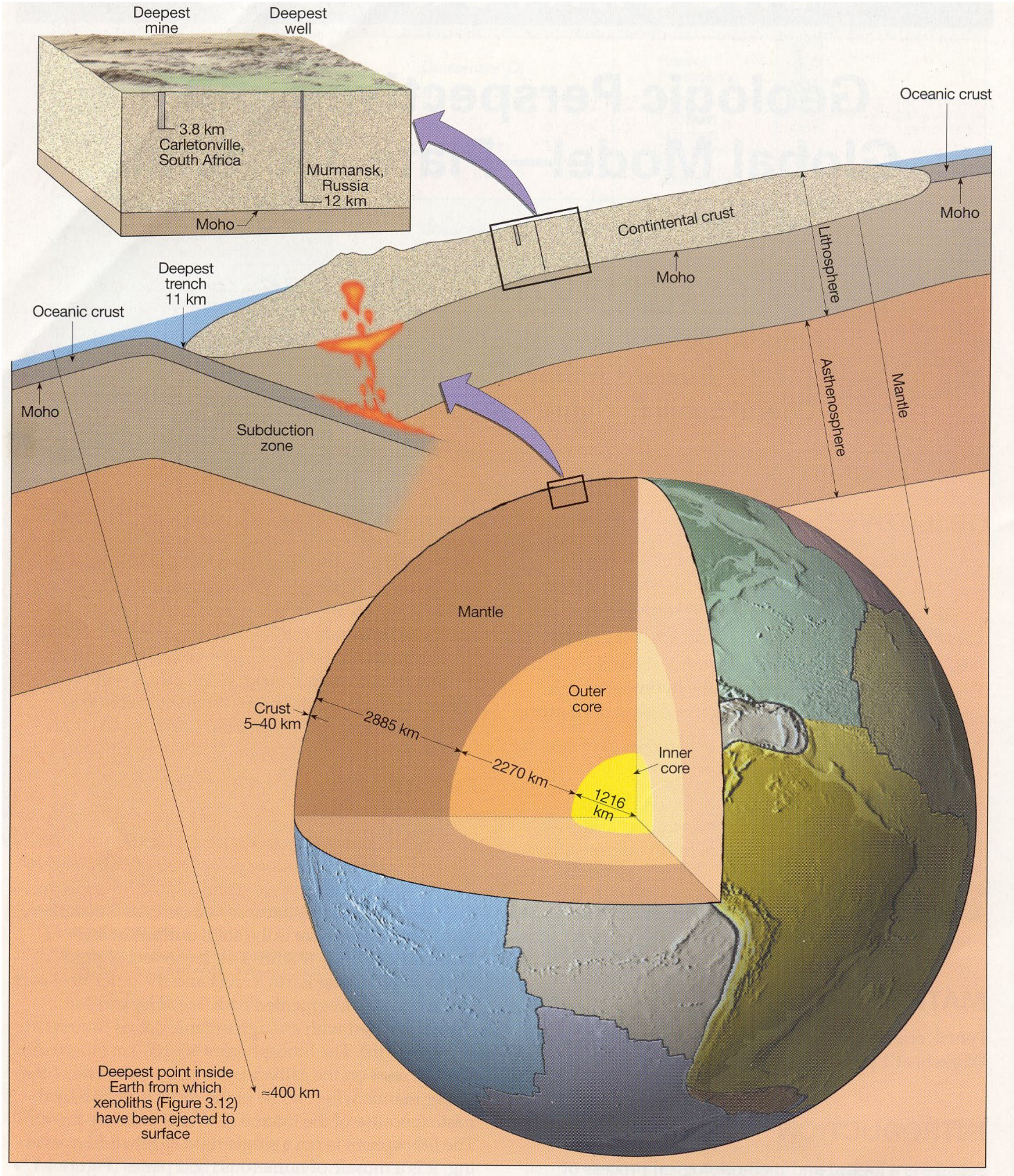


Figure 2 Structure of the Earth (after Anders et al., 1997)

The solid outer zone of the Earth (crust and upper mantle) is sometimes called the *lithosphere*. It is rigid, 60-100 km (40-60 miles) thick and it is believed to consist of 12 major plates slowly moving ("floating") laterally over the Earth's surface (Fig. 3). Movement of these plates is believed to be driven by the flow of material in a layer of the mantle that directly underlies the lithosphere, and is called the *asthenosphere*. Rock in the asthenosphere is soft, plastic, and flows like toothpaste because it is near its melting point. Plate movement is believed to be due to convection cells in the asthenosphere. The system consisting of the lithosphere and asthenosphere is in a state of equilibrium sometimes called *Isostatic Equilibrium*. There are areas of the Earth where lithospheric plates are formed, areas where they collide and form mountain ranges, areas where they depart and form oceans and basins, and areas where they are destroyed (and somewhat recycled) such as in subduction zones. The zones between plates, called *plate boundaries*, are regions where earthquakes and volcanic activity commonly occur. The *plate tectonics* model reinforces the concept that the Earth is a dynamic, ever-changing planet.

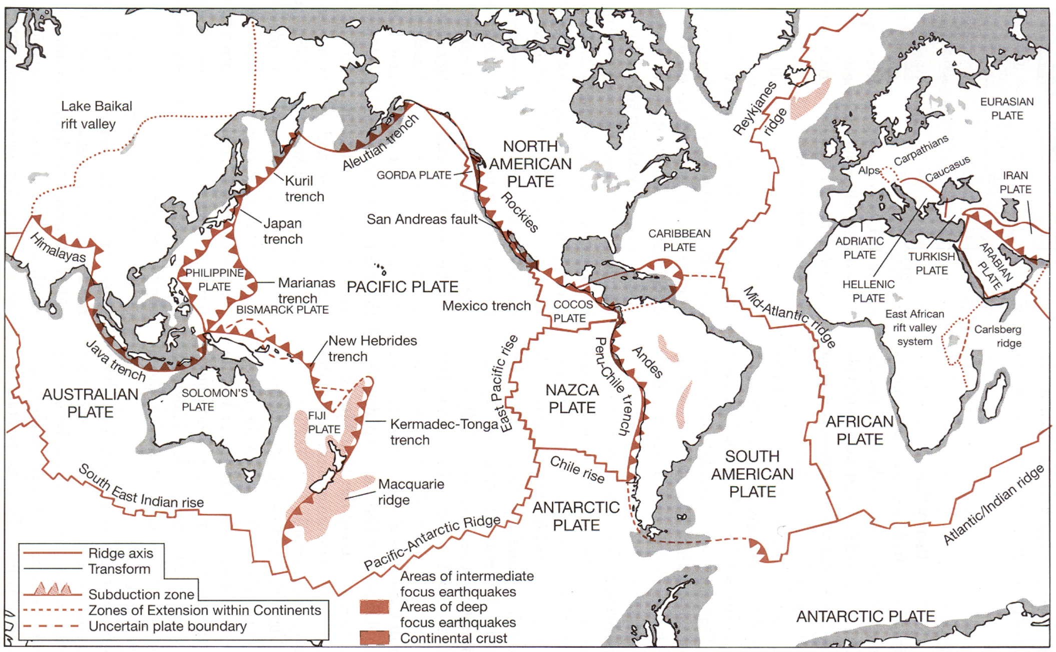


Figure 3 Plates and plate boundaries of the Earth (after West, 1995)

The zone of water at the surface of the Earth consisting of the oceans, lakes, streams, and rivers is called the *hydrosphere*. Absorbed air and particles of rock as sediment are also found in the hydrosphere. The average depth of the oceans is 3,794 m (12,447 ft), more than five times the average height of the continents. The mass of the oceans is about 1.35 x 10^{18} metric tons. A relatively small amount of Earth's water penetrates into the lithosphere and is called *ground water*; which is very important for water resources and in engineering projects.

The gaseous envelope around the Earth is called the *atmosphere*. The envelope of air contains absorbed water and small quantities of rock as dust, which may act as centers for the condensation of water vapor as clouds or fog. The chief component (78% by volume) of the atmosphere is nitrogen, but this gas is almost inert, as are the tiny amounts of argon, neon, helium, krypton, xenon, and other rare gases. The gases significant to man are oxygen (21% by volume) and carbon dioxide, which is the only gas less abundant in the atmosphere than in the hydrosphere. Water vapor (measured as *humidity*) is present in the air. The atmosphere has thickness of more than about 1,100 km (more than 700 mi).

The *cryosphere* is the snow and ice that forms from freezing parts of the hydrosphere or atmosphere. Most of it exists in the polar ice sheets (continental glaciers), permafrost (permanently frozen moisture in the ground), and sea ice (ice in the oceans).

The *biosphere* is the living part of the Earth, the part that is organic and self-replicating. It is all of the plants and animals on Earth. We belong to the biosphere.

The Earth is a living planet in/on which multiple physical and chemical processes of change take place (see Table 2). Of critical importance to planet Earth is the *hydrologic (water) cycle* (Fig. 4), which involves the evaporation of water (mainly from the oceans), the circulation of that water by air current over the continents, precipitation as rain or snow, and return of most of it to the sea under gravity.

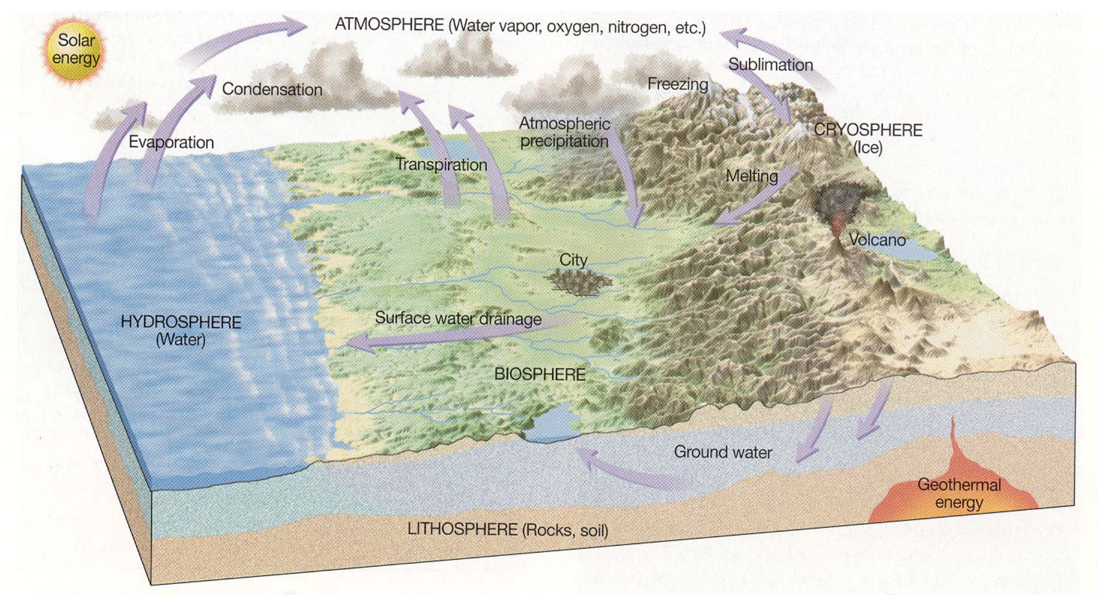


Figure 4 The hydrologic cycle (after Anders et al., 1997)

COMMON PROCESSES OF CHANGE		
Process	**Kind of Change**	**Example**
Melting	Solid phase changes to liquid phase.	Water ice turns to water.
Freezing	Liquid phase changes to solid phase.	Water turns to water ice.
Evaporation	Liquid phase changes to gas (vapor) phase.	Water turns to water vapor or steam (hot water vapor).
Condensation	Gas (vapor) phase changes to liquid phase.	Water vapor turns to water droplets.
Sublimation	Solid phase changes directly to a gas (vapor) phase, or gas (vapor) phase changes directly to solid phase.	Dry ice (carbon-dioxide ice) turns to carbon dioxide gas, or the reverse.
Dissolution	A substance becomes evenly dipersed into a liquid (or gas). The dispersed substance is called a solute, and the liquid (or gas) that causes the dissolution is called a solvent.	Table salt (solute) dissolves in water (solvent).
Vaporization	Solid or liquid changes into a gas (vapor), due to evaporation or sublimation.	Water turns to water vapor or water ice turns directly to water vapor.
Reaction	Any change that results in formation of a new chemical substance (by combining two or more different substances).	Sulfur dioxide (gas) combines with water vapor in the atmosphere to form sulfuric acid, one of the acids in rain.
Decomposition	An irreversible reaction. The different elements in a chemical compound are irreversibly split apart from one another to form new compounds.	Feldspar mineral crystals decompose to clay minerals and metal oxides (rust).
Dissociation	A reversible reaction in which some of the elements in a chemical compound are temporarily split up. They can combine again under the right conditions to form back into the starting compound.	The mineral gypsum dissociates into water and calcium sulfate, which can recombine to form gypsum again.
Chemical precipitation	A solid that forms when a liquid solution evaporates or reacts with another substance.	Salt forms as ocean water evaporates. Table salt forms when hydrochloric acid and sodium hydroxide solutions are mixed.
Photosynthesis	Sugar (glucose) and oxygen are produced from the reaction of carbon dioxide and water in the presence of sunlight (solar energy).	Plants produce glucose sugar and oxygen.
Respiration	Sugar (glucose) and oxygen undergo combustion (burning) without flames and change to carbon dioxide, water, and heat energy.	Plants and animals obtain their energy from respiration.
Transpiration	Water vapor is produced by the biological processes of animals and plants (respiration, photosynthesis).	Plants release water vapor to the atmosphere through their pores.
Evolution	Change through time.	Biological evolution, change in the shape of Earth's landforms through time.

Table 2 Common processes of change on Earth (after Anders et al., 1997)

Some water facts for your information:

- If Earth were the size of an egg, the total volume of water would be equivalent of one drop. Of this total, only about one-third of one percent is actually available to humans as fresh water for drinking and irrigating (water in lakes, rivers, and the accessible water table below ground).

- A human being can live several weeks without food, but without water, one can expect to live up to 10 days.

- Earth's total volume of water; some 1,360,000,000 km^3, would cover the globe to a height of 2.7 km (1.6 miles) if spread evenly over its surface. But more than 97% is seawater, 2% is locked in ice caps and glaciers, and a large proportion of the remaining 1% lies too far underground to exploit.

- More than 75% of the fresh water on the Earth's surface is frozen in the Antarctic ice cap.

- The Pacific Ocean is 25% larger than the entire land surface of the world combined.

- The Amazon, the largest river in the world, discharges 7,060,000 ft^3 of water per second. Its volume nearly equals that of all the other large rivers combined.

- The average human has about 50 liters (50 quarts or 12.5 gallons) of water in his/her body. Most of this water is found between the cells, bathing and lubricating them. The wettest part of the body - blood – is 83% water; the driest - tooth enamel - is 2%.

- The hydrologic cycle uses more energy in a day than humankind has generated throughout history.

- At any one time, only about 0.005% of the total water supply is moving through the hydrologic cycle. A drop of water spends about nine days passing through the air; once it falls as precipitation, it may remain in a glacier for 40 years, in a lake for 100 years, or in the ground from 200 to 10,000 years. A water molecule may remain in the ocean for 40,000 years before being cycled, but eventually, every drop of water on Earth is moved through the hydrologic cycle.

For us engineers, most (if not all) of our activities take place in the upper part of the crust, either at the ground surface or underground. Some of the deepest mines (such as in South Africa) are at depths of up to 3.8 km (12,500 ft.). The deepest oil wells penetrate little more than 6 km (4 mi). Some deep exploratory drilling programs in Russia and Germany have reached depths of 12 km (7.5 mi). Over such large depths, we need to take into account the increase in pressure and temperature that arises as we go deeper into the crust. The rate of temperature increase with depth is also called the *Geothermal Gradient.* The average geothermal gradient is of the order of about 3° C for each 100 m (30° C/km) of depth in the upper part of the crust. It is, however, not constant and varies a lot from one geological formation to another.

Population Growth

One of the main concerns of engineers is the improvement of mankind's condition. It is important, therefore, to understand what mankind's condition is today, and to understand the magnitude of population growth. Population growth applies pressure on the environment due to the increasing demand for water, soils, grain production, livestock, etc. It also applies pressure on the infrastructure, as more roads, dams, bridges, etc. have to be built.

You should be aware that, in the next two decades, almost 2 billion additional people will populate the Earth, a number roughly equivalent to the world's total population in 1940. This growth will create demands (on an unprecedented scale) for energy producing, food supplying, land stabilizing, water preserving, transportation providing, materials handling, waste disposing, earth moving, health caring, environmental cleansing, living, working and structural facilities. Also, geological hazards such as earthquakes will likely have more importance on human lives.

As discussed by P. H. Rahn in Chapter 1 of his book "*Engineering Geology- An Environmental Approach*", the growth of human population is exponential. It is believed that mankind evolved 2 million years ago. By 1 AD, the population was around 250 million and increased to 500 million (doubled) by 1650. It then doubled to 1 billion around 1850, doubled again to 2 billion by 1930, and doubled again to 4 billion by 1975. The Feb. 2019 world population is about 7.6 billion.

Population Statistics Web Sites:

- Real Time World Statistics
- http://www.census.gov/ipc/www/idb
- http://www.gapminder.org/world/
- http://www.infoplease.com/ipa/A0873845.html

Sometime at the end of October 2011, the population of the world crossed the 7 billion level (Fig. 5). Looking ahead, the UN expects the population to reach 8 billion by 2025, 9.3 billion by 2050, and 10 billion sometime between the years of 2085-2100. Another opinion in the literature is that the world's population will stabilize around 9 billion or even less by mid-century due to marked decreases in fertility rates in both developed and developing countries. Today, the annual world's population growth is about 1.08%; it takes about 13 years to add 1 billion extra humans to the planet with an increase of about 80 million people per year. Furthermore, the world population is about equally distributed in urban and rural areas, and it is expected that about two-thirds of humanity will live in towns and cities by 2050.

Population increase is not uniform and varies a lot from country to country. Note that the countries with rapid growth rates are developing countries. Another important parameter is the distribution of people according to age within a given country.

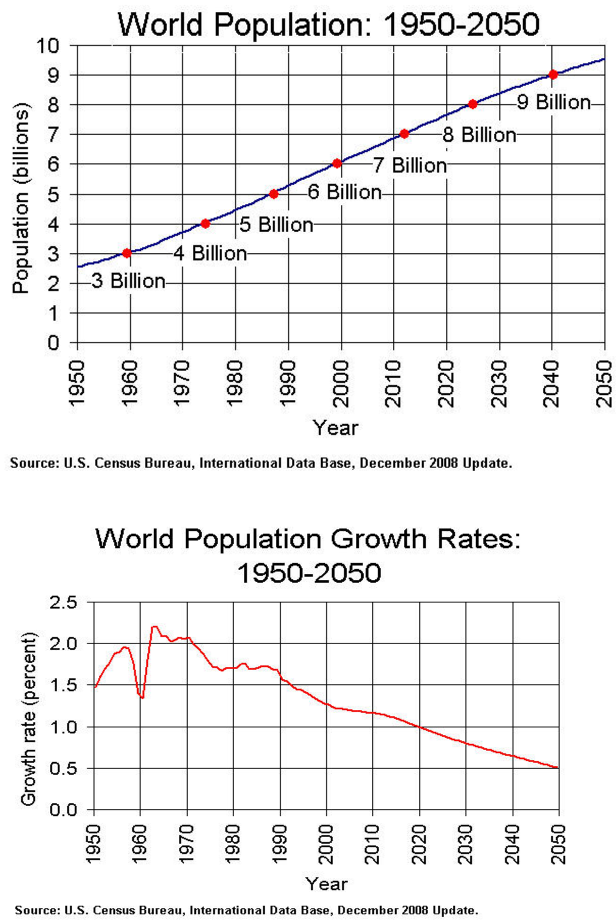


Figure 5 Expected (a) World population, and (b) World Population Growth Rate

Most of the population growth expected over the next 40-50 years will most likely occur in the developing world and in cities which will result in various challenges for every continent. In Africa alone, population is expected to increase from about 1 billion today to 2 billion in 2050. Urban population in Asia and Africa is expected to double from 1.7 billion in 2000 to 3.4 billion in 2030. This population growth across our planet will create unprecedented demands for energy, food, land, water, transportation, materials, waste disposal, earth moving, public health care, environmental cleanup, telecommunications, and infrastructure. The role of engineers will be critical in fulfilling those demands at various scales, ranging from small remote communities to large urban areas (megacities), mostly in the developing world.

It must be emphasized that the demands associated with population growth in the near future supplement what we already have today; a planetary *baseline* where 11% of the world's population lacks access to improved sources of clean water; 36% lacks access to improved sanitation; 43% either doesn't have enough to eat or has too much; 25% of adults are illiterate; 20% lacks access to clean energy; and 20% lacks adequate housing. To keep up with the demand of the world's population, it is estimated that food production will have to increase by 50 % by

2030 and 75% by 2050 which will double the demand for water and food production by 2050. In regard to water, the OECD has estimated that by 2030, almost half of the population will be living in areas that are water stressed with water demand outstripping *current* supplies by 40%.

Population growth will also require investment in human capital among the planet's young people (today 43% of world population is below the age of 25 according to the UNFPA, and 1.3 billion of them live in developing countries) by improving the quality of education and health services they receive and giving them capabilities to invest into their future and start a productive and healthy working life. As the population continues to grow, so too does the amount of waste produced. Currently, 80% of sewage in developing countries is untreated and disposed into the environment, resulting in the pollution of surface and underground water. The disposal of waste is expected to double over the next 20 years in lower income countries.

Due to population growth, stress on the environment and on our natural resources is expected to increase in the near future and will be more damaging to the Earth's human population and its life-support systems than ever before. The resulting environmental degradation will not only be a problem for industrially wealthy nations; it will become a major issue for developing countries as they become trapped in a downward spiral of ecological and economic decline and become more vulnerable to natural and non-natural hazards. As already remarked twenty years ago in the 1992 Rio Summit, and reaffirmed at the Rio+20 meeting in 2012, we are living in a world in which human populations are more densely populated, consuming more, are more connected, and in many parts are more diverse than at any time in history. Many of our living systems and cultural systems are in jeopardy as the increasing population results in a reduction in biodiversity, increasing ecological stress, and in general, creates impoverishment of life on Earth.

Dramatic variations in climate change leading to extreme drought or floods, environmental degradation associated with rogue economic development, and the recent international economic crisis are exacerbating the situation, especially for those at the bottom of the economic pyramid As noted in the *2005 World Resources* report by the World Resource Institute, "ecosystems are – or can be- the wealth of the poor" and damaging ecosystems has huge consequences on their livelihood. As remarked by the World Bank in its recent 2012 report on *Inclusive Green Growth*, "the damage done by environmental degradation is costly for an economy: equivalent to 8% percent of GDP across a sample of countries representing 40% of the developing world's population."

Over the past twenty years, there has been much discussion about sustainable development and how mankind can live within existing resources and life support systems. According to the *Global Footprint Network* on average, we are using the equivalent of 1.5 planets for the resources we need and the disposal/absorption of our waste. Another way of looking at the global footprint is that it takes our planet one year and six months to regenerate what we use (and want) in one year. Projecting this over the next 20 years, it is estimated that we will need two planets by 2030. This threshold has already been exceeded in wealthy countries such as the U.S. which is operating as if it has five planets available to support its life-style. This poses a serious question:

How do all humans, under such constraints, have fulfilling lives, meet their basic needs, and live with dignity without degrading the eco-systems and their services in the years to come?

According to the World Watch Institute (Brown et al., 1996), a *sustainable economy* is such that "…human deaths and births are in balance, soil erosion does not exceed the natural rate of new soil formation, tree cutting does not exceed tree planting, the fish caught do not exceed the sustainable yield of fisheries, the cattle on a range do not exceed its carrying capacity, and water pumping does not exceed aquifer recharge. It is also an economy where carbon emissions and carbon fixation are also again in balance. The number of plant and animal species lost does not exceed the rate at which new species evolve." A stable population is defined as one with a growth rate below 0.3%.

The growth of the world population can be modeled using the so-called *Exponential Model*. It is the same model that you would use to calculate how your money increases in your savings account, or to determine the decay of a radioactive element.

For instance, let N_o be a certain initial quantity and let x be the *percentage* increase of that quantity per year. A year later, the quantity will be $N_o\,(1+10^{-2}x)$. After a period of t years (and assuming the same percentage increase during that period), it will be equal to

$$N = N_o\,(1+10^{-2}\,x)^t = N_o\,e^{\lambda t} \qquad (1)$$

with

$$\lambda = \ln(1+10^{-2}\,x) \quad . \qquad (2)$$

Let T be the *doubling time*, i.e. the time is takes for N to be equal to $2N_o$. According to equation (1)

$$T = (ln\ 2)/\lambda. \qquad (3)$$

As a first numerical example, suppose that you deposit \$1,000 for 5 years at 12%/year (fixed) interest. Substituting $x = 12$ into equation (2) gives $\lambda = ln\ (1.12) = 0.1133\ \text{yr}^{-1}$. Substituting this value of λ into equation (1) with $N_o = 1{,}000$ and $t = 5$ yr, gives $N = \$1{,}726$. Your initial money would double after $T = 6.1$ yr.

As a second numerical example, consider the population of China, which in 1980 was 1.24 billion. Historically, that population has doubled every 49 years. What is the percentage increase per year? Substituting $N = 2N_o$ and $t = 49$ yr into equation (1) gives $\lambda = 0.01415\ \text{yr}^{-1}$. Using equation (2), we find that $x = 1.42\%$.

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Homework Assignment: (Due October 2, 2020)

1) The Earth makes one complete revolution about the sun in 365.24 days. Assuming that the orbit of the Earth is circular and has a radius of 93,000,000 miles, determine the velocity of the Earth.

2) The Earth makes one complete revolution on its axis in 23.93 hours. Knowing that the mean radius of the Earth is 3,960 miles, determine the linear velocity of a point at the surface of the Earth located (a) at the Equator, (b) on Baseline Road in Boulder, Colorado.

Use equations (1) and (2) to answer the following questions taken from "*Engineering Geology-An Environmental Approach*" by P. H. Rahn (1996). Use Real Time World Statistics data.

3) Assuming that the Earth has an average radius of 6,400 km (4,000 miles). (a) Calculate its land area, (b) Using present World population growth rates, determine how many years will elapse before one person will have 1 m^2 of land ("standing room only").

4) How many additional people are on Earth every minute in 2018?

5) It has been proposed to colonize space with Earth's excess population. In the year 2018, how many spaceships would have to lift off every day in order to evacuate the increase in the World's population? (Assume 100 people per spaceship).