

Lab 3: Population -- People at Risk

In recent years, the human population of planet Earth has increased dramatically. The world's population was estimated to be 5.6 billion in 1994. As the table below shows, human population did not attain a billion until 1804. Since that time the Earth's population has grown rapidly. For example, whereas it took several million years before a billion people inhabited the Earth only an additional 183 years were necessary to reach 5 billion.

Table 1: Population growth over time

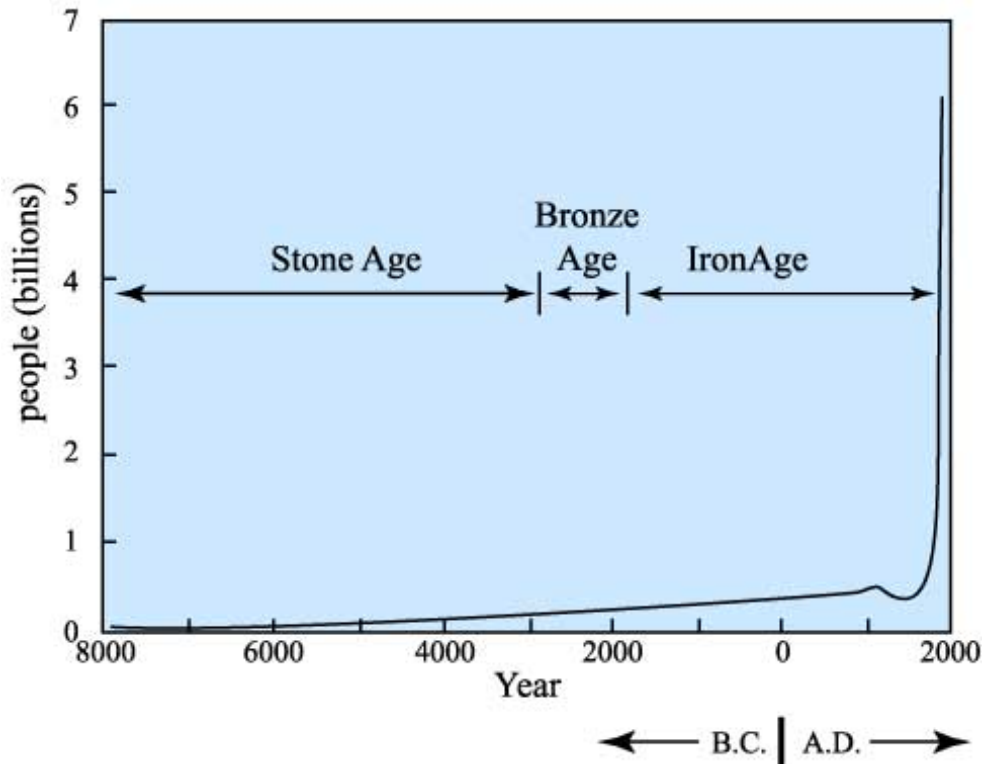
population	year	years to
1 billion	-	millions
2 billion	1927	123
3 billion	1960	33
4 billion	1974	14
5 billion	1987	13
6 billion	2004	17

This type of increase is exponential growth. Population growth is, however, slowing, particularly in the developed nations. Growth rate peaked in the late 1960s at about 2% per year, but has declined to approximately 1.6% at the present. Even at this lower growth rate, 86 million people are added to the world's population each year. Despite the slowing of the rate of population growth, the numbers of humans inhabiting Planet Earth is increasing substantially. Housing and feeding this large number of people often necessitates situating large population centers in regions subject to a variety of geologic hazards. Clearly this increase in population has important implications for the numbers of people affected by future geologic hazards. Even today roughly 80 % of the world's population lives close to the Pacific rim, a region susceptible to a variety of geologic hazards. This lab will:

- examine the mathematical equation that describes population growth;
- investigate the concept of doubling time;
- consider how changing growth rate affects population increase;
- determine population density and how it relates to geologic processes; and
- review the population characteristics of a variety of nations prone to geologic hazards.

Exponential Growth

Since the 18th century, there has been a dramatic increase in human population. The explosion in human population is an example of **exponential growth**. It differs from the more familiar linear growth in that the rate of growth increases rapidly as the process progresses. Exponential growth can always be recognized by the initial slow change in the curve followed by much more rapid changes as time passes. The slow growth at the beginning often leads to a lack of awareness of the consequences of future growth.



Exponential growth is characteristic of many natural phenomena, e.g. growth of human populations, reproduction of bacteria, decay of radioactive elements and accumulation of daughter elements. Thus, it is important to understand for things as diverse as population planning, the storage of nuclear waste and the radiometric dating. To describe population growth, the constants in the exponential equation are modified to reflect the conditions of growth thereby producing the population growth equation.

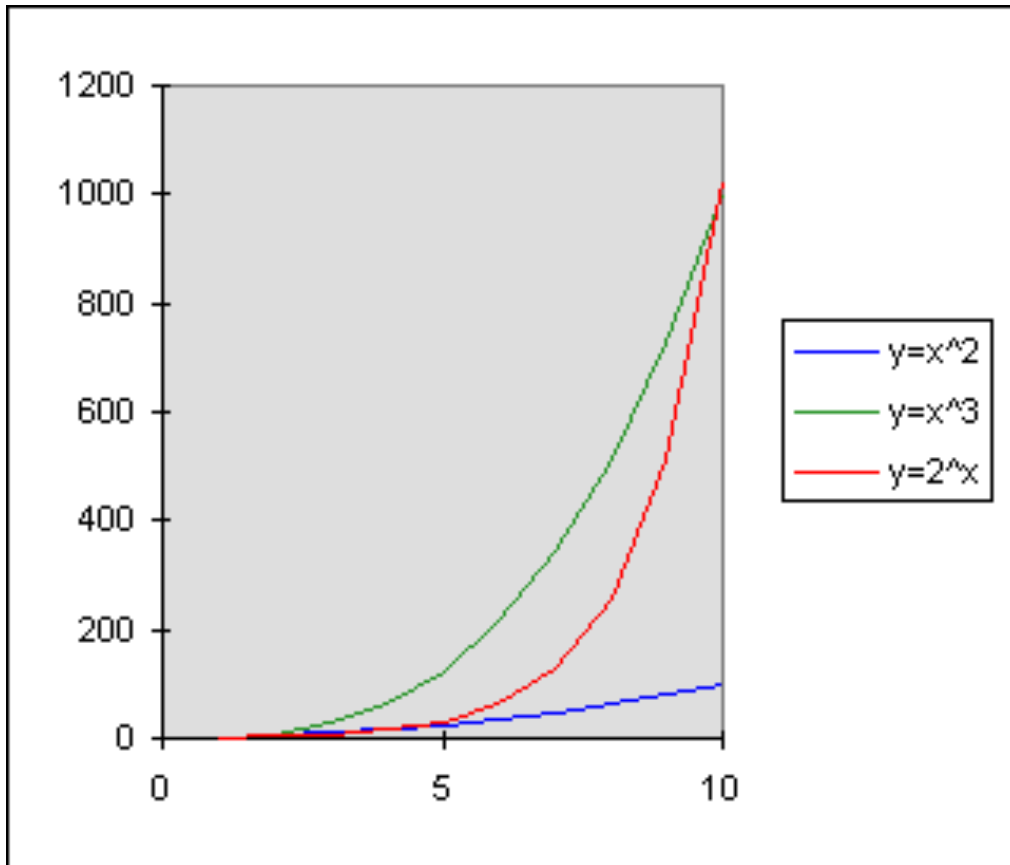
Exponential Growth Equation

Exponential growth is represented by an equation of the following form:

$$y = cX^n$$

In this equation, c is the pre-exponential constant and x is the variable raised to the exponent n . The form of the curve defined by this equation is determined by the value of

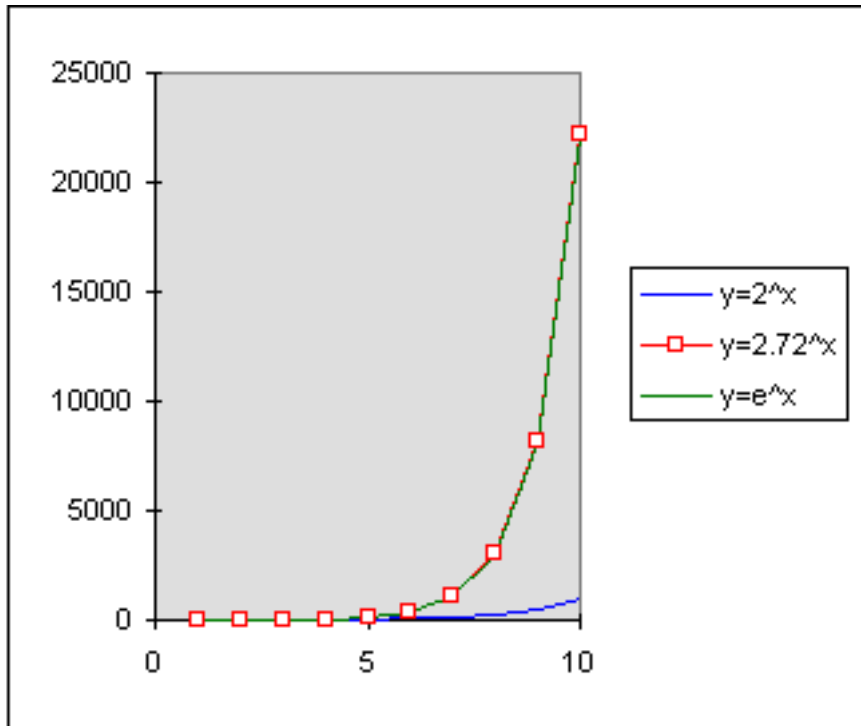
the exponent, i.e. n. Larger values of n produce steeper curves whereas shallower curves are generated for smaller n. The effect of changing the value of the exponent is illustrated in the diagram below:



In the expressions graphed above, the number raised to the exponent is the variable, i.e. x, and the exponent is a constant. An exponential curve can also be defined where the number raised to the exponent is constant and the exponent the variable. An example of such an equation is:

$$y = 2^x$$

This equation is plotted as the blue curve on the diagram. Notice when compared to the exponential curve with a variable base ($y=x^2$ or $y=x^3$) that this form of the equation produces a more concave curve. A special form of exponential curves is defined when the number raised to the power has a value of 2.7183.... This equation is plotted as the green curve on the graph below.



Despite the small difference between this number and 2, there is a substantial difference in the exponential curves using these two numbers as bases (see graph above). Mathematically, this number is represented by the letter *e* and the exponential equation is commonly expressed as:

$$y = ce^x$$

The position of this curve on top of the one for $y=2.7183x$ clearly shows that the two expressions are merely different ways of expressing the same mathematical relation. When the exponential of this type of equation is complex, it is often difficult to write it such that it is clear what terms are actually in the exponent. For simplicity, *e* is often represented by *exp* (for *exponential*) with the exponent enclosed in parentheses. Expressing the above equation in this form produces:

$$y = c \cdot \exp(x)$$

Population Growth Equation

Exponential growth is represented by an equation of the following form:

$$y = cx^n$$

To describe the growth of a nation's population, we must replace the general terms in this expression with those appropriate to population growth. The quantity we are interested in is the population at some time in the future. We can represent this quantity as $N(t)$ where N represents the number of people at time t . The term t represents a year, e.g. 2050. Thus, the $N(2050)$ would be the population in the year 2050. Replacing y (the dependent variable) in the exponential growth equation, we have:

$$N(t) = ce^n$$

To calculate this quantity, we need to know the population at some initial time t_0 . This quantity, represented as $N(t_0)$ or N_0 , replaces the pre-exponential term in the equation above. Substitution yields:

$$N(t) = N(t_0)e^n$$

Thus, if we knew the population of a country in 1986 and wanted to calculate the population increase from that starting base, $N(t_0)$ would become $N(1986)$ and we would replace it with the appropriate number for our calculation. Unlike simple exponential growth, the exponent in the growth term is no longer a simple integer. Rather, it is the product of the time interval (t) and the growth rate (r). With substitution, the population growth equation becomes:

$$N(t) = N(t_0)e^{rt}$$

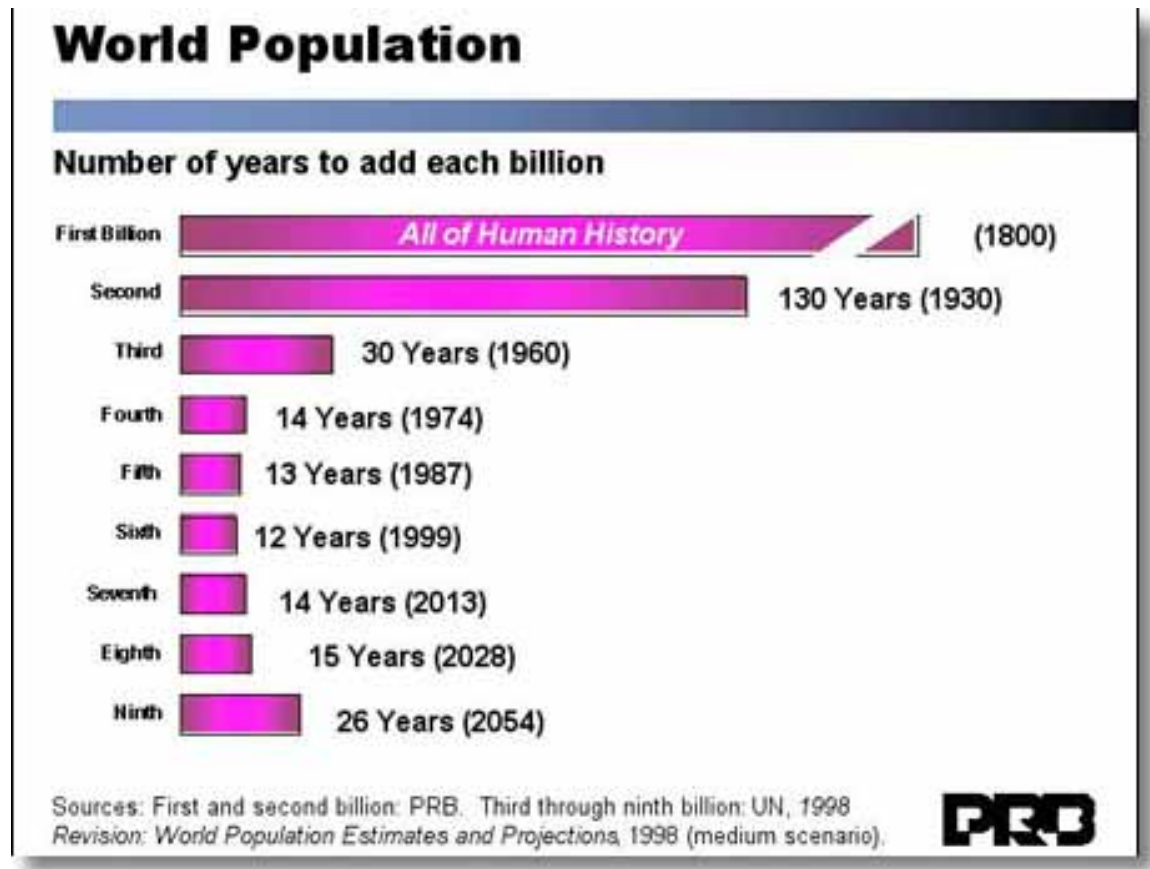
Noting that the time interval over which the population grew is simply the difference between the year of the initial population and the year we want to calculate the new population in, i.e. $t-t_0$, we have:

$$N(t) = N(t_0)e^{r(t-t_0)}$$

The above equation describes the growth of a population from an initial amount in the year t_0 to year t assuming a growth rate of r %/year. If growth rate, r , is replaced by the decay constant, this equation describes radioactive decay.

Doubling Time

Doubling time is the time it takes for a population to double in size. Anything that grows exponentially, e.g. population, bank account, bacteria, etc., involves doubling time. Despite its simplicity, doubling time is a powerful concept that is useful for conveying the consequences of exponential growth.



Throughout human history, population doubling time has steadily decreased. Doubling time can be calculated from the growth rate.

Calculating Doubling Time

When discussing growth, it is often useful to know the time required for a quantity to double given a constant rate of growth, i.e. the **doubling time**. This time interval can be determined easily from the growth equation. Recalling the growth equation, we have:

$$N(t) = N_0 e^{rt}$$

The population doubles when $N(t)$ equals twice N_0 . Making this substitution into the growth equation produces:

$$2N_0 = N_0 e^{rt}$$

Knowing the initial population and the growth rate, the unknown to be solved for is t , that is the doubling time. Dividing through by N_0 , the equation above can be simplified to:

$$2 = e^{rt}$$

Unfortunately, this equation can not be solved algebraically because t is contained in the exponent of e . If we take the logarithm of both sides of this equation, we will move t out of the exponent and thus be able to solve for it. Because we are dealing with e , the logical logarithm to use is the natural log, i.e. \ln . Using the law of logarithms, we obtain:

$$\ln(2) = \ln(e^{rt})$$

$$\ln(2) = rt\ln(e)$$

Because $\ln e$ equals one and $\ln(2)$ is 0.68931, solving the relation for t yields:

$$t = \frac{0.6931}{r}$$

where r is the growth rate. Clearly, the smaller the growth rate the longer the doubling time and the larger the growth rate the shorter the doubling time. For China, the doubling time is approximately 26 years for a growth rate of 2.7% but increases to 63 years for the lower growth rate. Clearly growth rate is an important factor when considering a nation's future population growth and Earth resource needs. Doubling time can also be estimated from the relation $70/G$ where the growth rate (G) is expressed as a percent/year not as a rate. Thus, if you have \$100 in the bank and it is growing by 7 % (that is a 7% interest rate), you can easily determine when you would have \$200. Using the simpler form of the doubling relation, your money would double in 10 years ($70/7$).

Population Density

The number of people affected by a geologic event or resource development are determined by the population density. Obviously, the greater the population density, the more people impacted by a particular event in a given area.



The population of Nigeria, an important oil-producing country, varies considerably from region to region.

Population density, defined as people per area, is a measure of how closely peoples are packed in an area. It is usually measured in persons per square kilometer ($\text{people}/\text{km}^2$) or persons per square mile ($\text{people}/\text{mi}^2$).

Calculating

The formula for calculating density is simply: population divided by area:

$$\text{population density} = \frac{\text{people}}{\text{area}}$$

If a region has 500 people living in it and it covers 250 km^2 , the population density is:

$$\begin{aligned}
 \text{population density} &= \frac{\text{people}}{\text{area}} \\
 &= \frac{500 \text{ people}}{250 \text{ km}^2} \\
 &= 2 \frac{\text{people}}{\text{km}^2}
 \end{aligned}$$

Variation

Population densities vary widely within a state, country and the world. The table below shows population densities for several selected countries.

Table 1: Population densities for some select countries.

region	population	area (km ²)	population density (population/km ²)
Canada	33,098,932	9,984,670	3
Brazil	188,078,227	8,511,965	22
United States	298,444,215	9,631,420	31
Indonesia	245,452,739	1,919,440	128
China	1,313,973,713	9,596,960	137
Nigeria	131,859,731	923,768	143
Germany	82,422,299	357,021	230
India	1,095,351,995	3,287,590	333
Bangladesh	147,365,352	144,000	1,023
Hong Kong	6,940,432	1,092	6,355

Even within a single nation, population densities can vary greatly. Table 2 illustrates how population density fluctuates in the United States.

Table 2: Population densities in the United States.

region	population	area (km ²)	population density (population/km ²)
New York City	8,008,278	1,214	10,194
Wyoming	506,529	253,347	2

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- [Johns Hopkins Population Information Program](#)
- [CIA World FactBook](#), a great source of information about the countries of the world.
- [U.S. Census Bureau](#), the federal agency responsible for counting the United States population and assembling a demographic snapshot of our nation. You can see current estimates for the world and U.S. populations, find statistics about all aspects of the U.S., search by region and create maps.
 - [U.S. and World Population Clocks](#), up-to-date estimates of the U.S. and world populations.
 - [International Data Base \(IDB\)](#), a data bank containing statistical tables of demographic, economic and social data for all countries of the world. You can get current population pyramids for any country.
 - [International Programs Center \(IPC\)](#), IPC assists in the collection, processing and analysis of statistics from all over the world.
- [Population Reference Bureau](#), The PRB is a population information resource agency based in Washington, D.C. It was established in 1929. This site provides a

wealth of information about population both globally and nationally. There is a good section in the Education area that presents many figures that illustrate current population trends. The site also has many data sheets showing the population characteristics of various nations.

- [UN Population Information Network \(POPIN\)](#), Information network about world population and other demographic statistics provided by the Un Population Division, Department of economic and Social Affairs. It is based at the UN headquarters in New York City.