

- Carrying Capacity of the Earth -

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Limiting Factor Model

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Summary

As the world's population continues to increase, severe concerns around sustaining future populations arise. These concerns are extremely pertinent considering the environmental stresses placed on the planet as humans consume resources like fresh water and habitable land, which gradually move us towards carrying capacity. As the problem states: "the carrying capacity of a biological species in an environment is the maximum population size of the species that the environment can sustain indefinitely, given the food, habitat, water, and other necessities available in the environment."

The goal of our model was to produce an approximate value for Earth's carrying capacity based on factors crucial to sustaining human life, i.e. food, freshwater and land. These are the factors we consider absolutely essential to human life at a low standard of living. A shortage of one of these factors cannot be compensated for by an excess of the others, thus our model identifies which resource is most finite and likely to be depleted first, thus reaching carrying capacity. This is the limiting factor.

Our first section (Question 1) identifies our three major factors, and analyzes them in terms of maximum quantities: food in kilocalories, land in km^2 and freshwater in litres. Land is further categorised into land for habitation and land for agriculture. Freshwater that is treated is considered potable water, which is suitable for drinking and household use, the rest being undrinkable but useful for agriculture and industry. Due to the difficulty in collecting our own data, we use external resources to analyse the requirements of freshwater, food and land from which we will develop our own model.

Our model (Question 2) is formed from these requirements. We modelled the resources required by each person per year against the number of theoretical people in a population on earth. On each graph is a horizontal line which represents the maximum yield of each factor (i.e. freshwater, food, land) we can produce per year. The intersection of our modelled line with the capping line is the carrying capacity of earth with respect to the factor. The factor which produces the lowest carrying capacity, i.e. depletes first, is our limiting factor.

In the third section (Question 3) of our report, we analyse the factors more closely. We also consider what conditions the world might be under in the future, such as global warming, environmental pollution and deforestation. These conditions will place added pressures to finding enough resources to sustain the growing population. We also consider lifestyle changes that people can make to decrease the resources required per person per year, to make more efficient use of the available ones.

Introduction

The carrying capacity of earth is an important issue for everyone living on this planet. Not only does it involve environmental, humanitarian and ethical plights, the outcome of our resource distribution in the years to come will influence everyone's quality of life. In the face of changing global climate and ocean acidification driven by greenhouse gas emission, the results of our model are susceptible to significant and adverse change.

It is important to plan ahead for our future generations, thus our model aims to present a holistic representation of the carrying capacity of earth with our current conditions and technologies, which are limited, and what it could be if the future changes in our conditions were realistically responded to with innovative and efficient technologies to ensure the most ideal distribution, production and consumption of our finite resources.

Note: All citations are placed in the appendices, and referenced like 'statistic [number]' with a corresponding number in the references.

Assumptions

1. Quality of life

Huge inequalities exist in the qualities of life between different countries on earth. We assume that the resources consumed by each individual in our model is the bare minimum required to ensure that the birth rate be equal to or greater than the death rate, thus complying with the definition of carrying capacity as "the maximum population size of the species that the environment can **sustain indefinitely**." For this reason, we have excluded healthcare and shelter as factors because while they affect one's quality of life, they do not affect carrying capacity.

2. Average consumption

People of different cultures, sizes and lifestyles consume and use food and water in different amounts. We assume that each person in our model requires approximately the average amount of freshwater, food and land for a person in their socio-economic bracket as stated by global statistics.

3. All data is accurate

The data we use is collected from reputable sources (see References, pg) but it is impossible to know the accuracy of the data without more intimate knowledge of the sampling and processing methods. We assume the relevant data is accurate and will compare it to similar studies from other sources to verify its credibility

4. Same proportion of resource consumption

As populations grow, the distribution of food, water and land may change. A small, wealthy suburb might have more land for habitation and less for agriculture, while a dense city will have less for habitation and more for waste management, water treatment and agriculture to feed its citizens. For consistency across our model, we

need to assume that the proportion of water, land and food required by humans stays the same across populations of different size.

5. Maximum available resources

We assume under current conditions and technologies that the maximum amount of freshwater is collected and treated each year, the maximum amount of food is produced (so the maximum amount of agricultural land that can be used, is being used, and there is enough water to irrigate it.) Note that these technologies and processes are flawed, so it is likely with today's inefficiencies the carrying capacity might be less than calculated, therefore larger maximum resources can be obtained by refining and innovating the processes.

6. Plant and phytoplankton life can be sustained

Oxygen is critical to life on earth for humans and other organisms. The rising presence of CO_2 in the atmosphere, and thus carbonic acid in the oceans, affects the abundance of plants and phytoplankton in our biosphere. Phytoplankton produces between 50-85% of the oxygen in our atmosphere, so we assume that in our models, oxygen is abundant and will be for the foreseeable future (though realistically this is disputable) because our flora populations are sustainable.

7. Even distribution of resources around the world

We assumed that all the resources analyzed in this report could be distributed relatively evenly across the world, and that resources can be easily transported efficiently and with minimal waste to where there is greatest need for them.

Factors Influencing Carrying Capacity

The factors we considered that could potentially limit Earth's carrying capacity were fresh water, food availability, and inhabitable area. Other factors which are crucial to sustaining life - such as oxygen levels or sunlight - were not considered, as these are largely available in excess quantities, and are therefore unlikely to limit the Earth's carrying capacity. We further analyzed fresh water, food availability, and inhabitable area with the models below.

WATER

When considering water as a factor that could affect the Earth's carrying capacity, we chose to focus on available fresh water sources, as current technology is largely unable to extract water trapped in glaciers, ice caps, etc. We developed the model below for analysing human use of water, considering factors like drinking water, household water, and industry. We chose not to incorporate ground water into our models because ground water sources are largely unsustainable at current rates of human consumption, and the problem clearly states *sustainable* carrying capacity.

$$W_{earth} = W_{fresh} + W_{salt}$$

This is a basic description of the distribution of water on earth - the total water is equal to the freshwater plus the salt water.

$$W_{fresh} = W_{favailable} + W_{ftrapped}$$

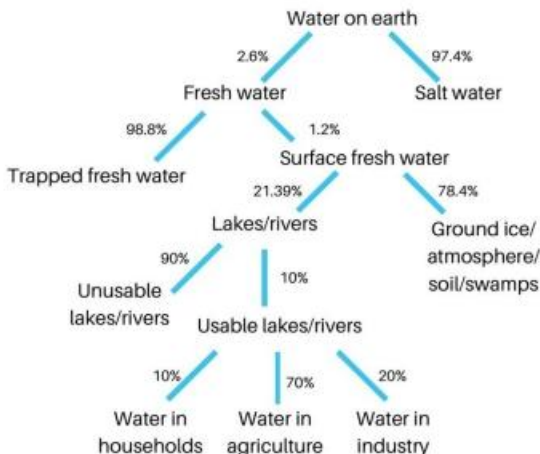
We can further break down the freshwater on Earth into the water that is easily accessible to us (e.g. lakes, streams, reservoirs) and those that are trapped in inaccessible locations (e.g. glaciers, ice caps.)

$$W_{favailable} = W_{agriculture} + W_{human} + W_{industry}$$

The freshwater that is freely available to us is put to several different uses - agriculture, industry, and human use (household, drinking.)

$$W_{agriculture} = W_{plant} + W_{animal}$$

Water used for agriculture can be further split into water put towards plant agriculture, and animal agriculture. Compiling the above equations into a flow diagram gives us this chart:



For this section of the report, we will focus on the water that we consume in our households, as water in industry is not essential to human life, and we analyze agricultural water later in this report. Using statistics for the total water on earth, and known percentages we devote to certain areas, we were able to analyse the potable/irrigation water we *could* theoretically produce each year, if we were to increase our treatment capacity.

Total water on Earth (litres) [20]	1.26E+21
Total freshwater on Earth (litres) [21]	$(1.26E+21 \times 0.025) = 3.15E+19$
Surface freshwater (litres) [21]	$(3.15E+19 \times 0.012) = 3.78E+17$
Rivers/lakes (litres) [21]	$(3.78E+17 \times 0.2139) = 8.085E+16$
Usable rivers/lakes (litres) [21]	$(8.085E+16 \times 0.1) = 8.085E+15$
Household use (litres) [21]	$(8.085E+15 \times 0.1) = 8.085E+14$
Annual consumption/person (U.S.) (litres) [23]	138992.6003
Annual consumption/person (N.Z.) (litres) [24]	82911.75
Annual consumption/person (median) (litres) [25]	34698.75
Annual consumption/person (minimum) (litres) [25]	18262.5

LAND

$$L_{earth} = L_{inhabitable} + L_{unusable}$$

This is a basic description of land area on earth - the total land area is equal to the inhabitable land area, plus the unusable land.

$$L_{inhabitable} = L_{inhabited} + L_{agricultural} + L_{unused}$$

We can further break down the inhabitable land on Earth into the land that is already inhabited, plus the land we *could* use for agricultural purposes, and the land that is currently inhabitable (but not suitable for agriculture), but unused.

$$L_{agricultural} = L_{animal} + L_{plant}$$

The agricultural land can be broken down into unused land that is suitable for agriculture, plus the land dedicated to the farming of animals (including the production of food for these animals) and the land dedicated to the farming of crops for human consumption. The relationships above are summarised by these charts: