- Carrying Capacity of the Earth -

Team #2019029

Limiting Factor Model

Contents

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 habitance and less for agriculture, while a dense city will have less for habitance 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.

$$W_{fresh} = W_{f_{available}} + W_{f_{trapped}}$$

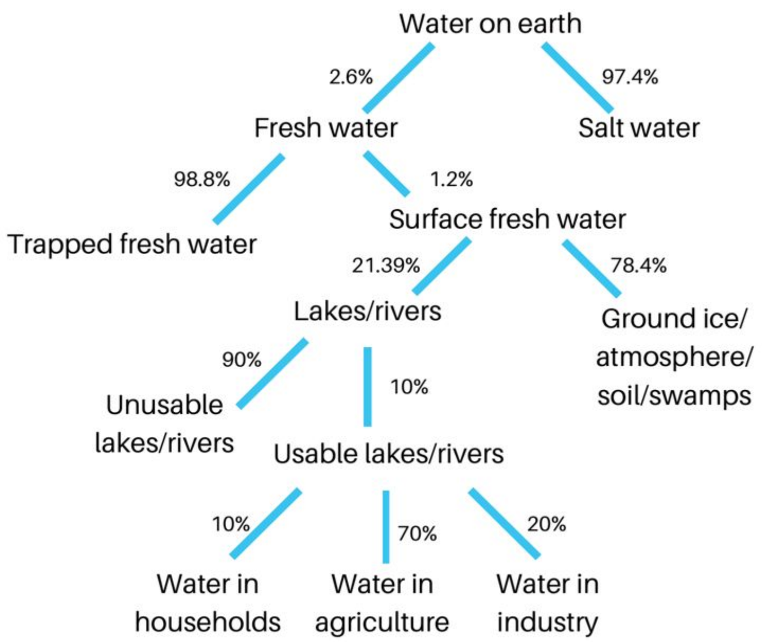
We can further break down the freshwater on Earth into the water that is easily accessible to us (e.g. lakes, streams, reservoirs) and those that are trapped in inaccessible locations (e.g. glaciers, ice caps.)

$$W_{f_{available}} = W_{agriculture} + W_{human} + W_{industry}$$

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*0.025)=3.15E+19
Surface freshwater (litres) [21]	(3.15E+19*0.012)=3.78E+17
Rivers/lakes (litres) [21]	(3.78E+17*0.2139)=8.085E+16
Usable rivers/lakes (litres) [21]	(8.085E+16*0.1)=8.085E+15
Household use (litres) [21]	(8.085E+15*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

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

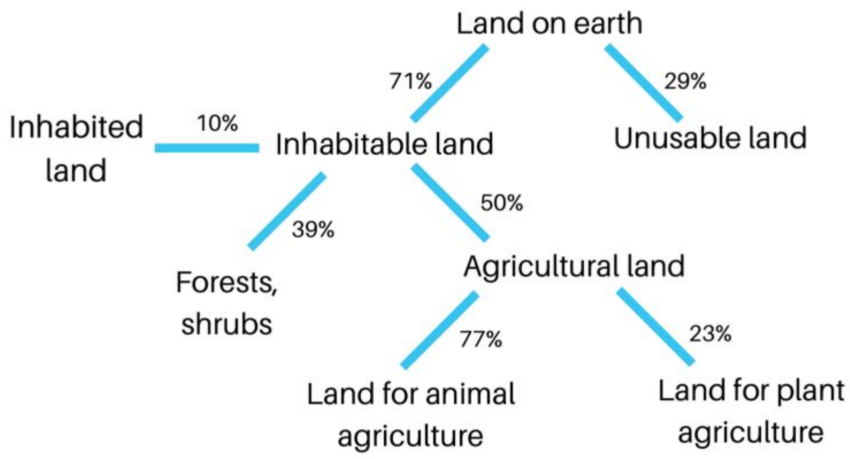
This is a basic description of land area on earth - the total land area is equal to the inhabitable land area, plus the unusable land.

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

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:



For this section of the report, we will focus on the land that we could use as living area, not for agricultural purposes. We assumed that we should not encroach any further on forests and shrubs for the environmental impact that this could have. We also took into account different levels of population density based on major cities around the world at different standards of living - Auckland, New Zealand, Lima, Peru, and Vienna, Austria. We then created the table below to calculate the amount of habitable land that could accommodate an increased human population:

Total land area on earth (m^2) [1]	1.489E+14
Inhabited land (m^2) [16]	(1.489E+14*0.071)=1.05719E+13
Population density (Auckland, people/m^2) [18]	0.00121
Area per person (Auckland, m^2)	(1/0.00121)=826.45
Population density (Lima, people/m^2) [17]	0.0035
Area per person (Lima, m^2)	(1/0.0035)=285.71
Population density (Vienna, people/m^2) [19]	0.0057
Area per person (Vienna, m^2)	(1/0.0057)=175.44

FOOD

Global food production is largely dependent upon the amount of water and agricultural land available. For our models for food production, we used statistics based on the kilocalories produced by a certain crop per unit area of land per year. With our previous models for agricultural land, we were able to find maximum food production in terms of kilocalories per year. We assumed that there would be excess water unsuitable for human consumption, as well as precipitation, that the limiting factor for agriculture is land area. We followed a similar approach to food production as we did for water and land, using statistics we found online for the kilocalories produced by different crops per meter squared per year.

All values per year.

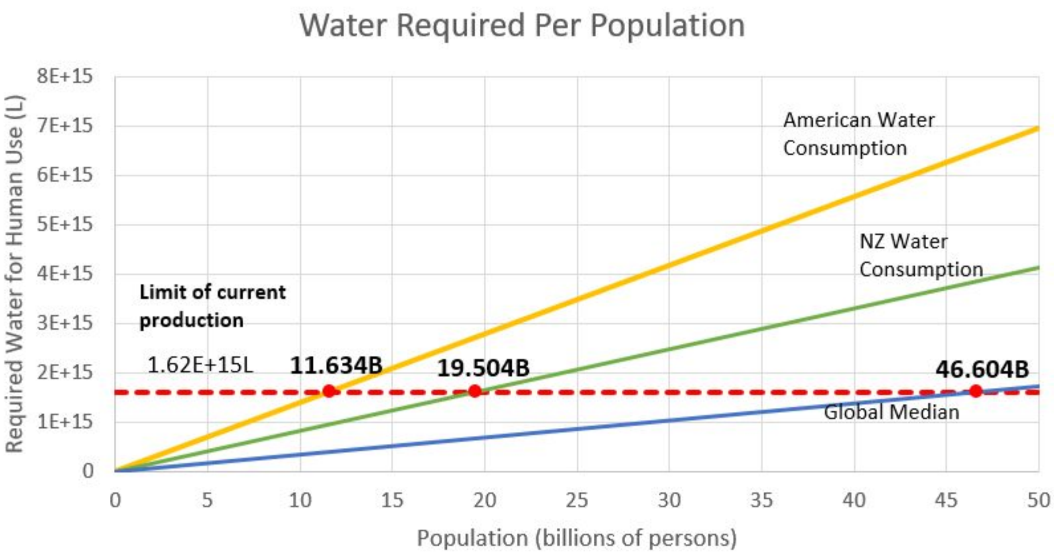
Total land on earth (m^2) [1]	1.49E+14
Used agricultural land (m^2) [2]	(1.49E+14*0.355)=5.29E+13
Potential agricultural land (m^2) [3]	(5.29E+13/0.36)=1.47E+14
Usable protein per m^2 of meat (g) [4]	4
Usable protein per m^2 of soybean (g)	29
Average protein per m^2	(4*0.77+29*0.23)=9.75
Average kilocalories per m^2 [6]	(9.75*4)=39
Total land food that can be produced (Kca)	(39*1.47E+14)=5.73E+15
Edible seafood worldwide (g) [42]	1.29E+14
Kilocalories from seafood	(1.0172*1.29E+14)=1.32E+14
Total food produced (calories)	5.86E+15
Average calorie intake (U.S.)	1387950
Average calorie intake (N.Z.)	1026353
Average calorie intake (Eritrea)	580747.5

General Model

Our model is split into the three factors we deem essential to human life: water, land and food. Since there are vast inequalities in how people consume water, we have chosen three to four different rates of consumption that have been calculated with respect to how people live in different parts of the world. This accounts for varying water consumptions in developed countries vs. developing countries, cities with different densities and food consumption in developed countries vs. developing countries.

As the population increases, the amount of resources required per year increases. However, there is a cap on the amount of resources that can be replenished or produced under today's conditions and technologies. This cap is represented as a constant value. When the line for the resources intersects the cap line, carrying capacity is reached.

WATER



$$CC_{water} = \frac{W_{humanuse}}{W_{person}} = \frac{\alpha W_{total}}{W_{day} \times 365.25}$$

where:

CC_{water} *is the carrying capacity of earth when considering water in persons*

$W_{humanuse}$ *is the amount of water for human use globally in Litres*

W_{person} *is the amount of water that one person requires in Litres*

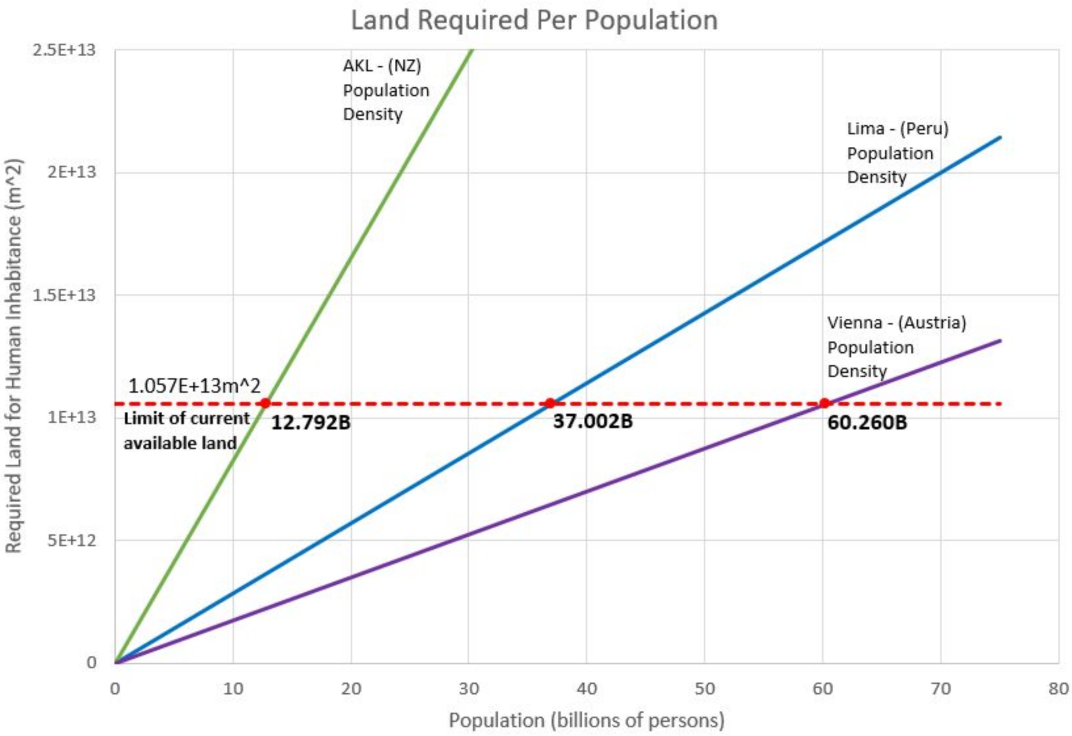
W_{total} *is the amount of water on earth in Litres*

$\propto$ *is the percentage of total water which is used for humans*

W_{day} *is the amount of water one person requires in one day in Litres*

The three lifestyles we considered in our water model are American, New Zealander and the global median, which is much lower than these two developed countries. The maximum amount of freshwater required for human use that the world's water collection and treatment systems can produce per year is 1.62 quadrillion litres. If everyone in the world consumed water under an American lifestyle (138992.6 litres per person per year,) we would reach carrying capacity when there are 11.6 billion people in the world. If we consumed like New Zealanders (82911.75 litres per person per year,) we would reach carrying capacity at 19.5 billion people. If we consumed water at the global median rate (34698.75 litres per person per year,) the carrying capacity of earth could be increased to 46.6 billion people.

LAND



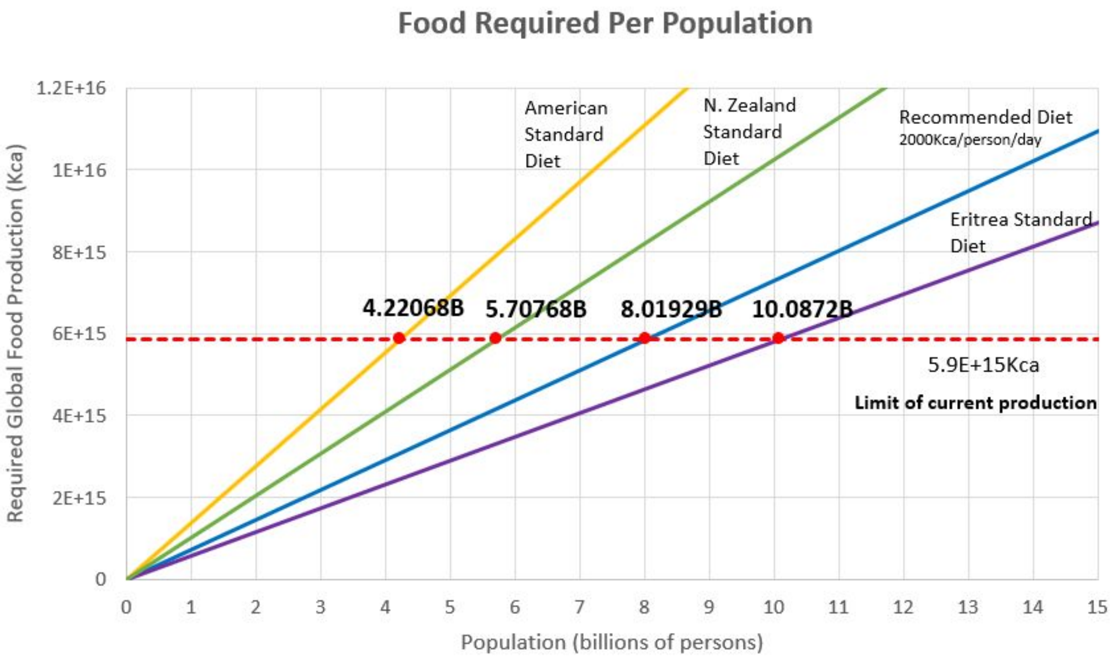
$$CC_{land} = \frac{L_{inhabitable}}{L_{person}} = \frac{\alpha L_{total}}{(P_{den})^{-1}}$$

where:

CC_{land} *is the carrying capacity of earth when considering land in persons*
$L_{inhabitable}$ *is the amount of land for human inhabitance in* m^2
L_{person} *is the amount of land that one person requires in* m^2
L_{total} *is the amount of land in the world in* m^2
$\propto$ *is the percentage of* L_{total} *that is inhabitable*
P_{den} *is the population density in people* m^{-2}

The three population densities we considered in our land model are Auckland density, which is relatively sparse (0.00121people/m^2), Lima (0.0035people/m^2) and Vienna (0.0057people/m^2) which is the densest. We chose Vienna as our measure of denser populations because despite its density, it is considered the world's most liveable city. [37] This shows that a high population can be comfortably sustained if other factors that affect quality of life are strong. Under today's conditions, the amount of inhabitable land is 0.71% of the total land on earth (1.058E+13m^2). The land used for agriculture is not considered in this model because the purpose of that land is to produce food, which is another factor that we model. This model looks at the carrying capacity of earth in terms of space required for human habitance, i.e. settlements. If the settlements of the world were as dense as Auckland we would reach carrying capacity when there are 12.8 billion people in the world. If the density of our settlements were that of Lima's, we would reach carrying capacity at 37 billion people. If our settlement density was that of Vienna's, the carrying capacity of earth could be increased to 60.3 billion people.

FOOD



$$CC_{food} = \frac{F_{produced}}{F_{person}} = \frac{(F_s \times 0.91548) + (L_{agri} \times F_{psm})}{F_{day} \times 365.25}$$

$where:$

CC_{food} *is carrying capacity of earth when considering food in persons*
$F_{produced}$ *is amount of food produced globally in Kca, p.a.*
F_{person} *is amount of food one person needs in Kca, p.a.*
F_s *is the weight of seafood produced globally in g, p.a.*
L_{agri} *is the amount of land used for agriculture in* m^2
F_{psm} *is the average amount of food produced per square metre in Kca*
F_{day} *is the amount of kilocalories* one person consumers per day

The four types of diets we considered in our land model are that of the United States of America, New Zealand, Eritrea and the recommended diet. Under today's conditions, the amount of food we can produce is 5.9 quadrillion kilocalories. If the calorie intake of the earth's population was that of an American's (1,387,950 calories per year), the carrying capacity would be 4.2 billion people. If global calorie intake was that of a New Zealander (1,026,353 calories per year) the capacity would be 5.7 billion people, 8 billion if we consumed the scientifically-recommended calories (730,500 calories per year) and 10 billion if we consumed calories like an Eritrean (580,748 calories per year.)

THE LIMITING FACTOR

From our three models, it is clear that food is the factor which is likely to limit the carrying capacity of the earth. That is to say, while land and freshwater are also finite resources, food is comparatively more scarce and likely to run out. This is because the time it takes for livestock and crops to mature, be slaughtered/harvested, processed, packaged, distributed and finally sold and consumed is lengthy. Agricultural land takes up 50% of the habitable land on earth, whereas urban settlements occupy just 10%. [15] 70% of available freshwater is used for agriculture, and 10% for household use. [22]

Hence it is clear the demands for food production are the greatest limiting factor for carrying capacity. The carrying capacity of earth was much higher when we modelled the proportion of land and water used by humans, but as low as 4.2 billion people when modelling food. Since these three factors are essential to human life, and the absence of one cannot be compensated for by the others, food scarcity is the issue which is likely to limit our carrying capacity.

CONCLUSION

In conclusion, assuming the world continues to consume food at the recommended number of calories, and the limits of food production remain constant under today's conditions and technologies, the carrying capacity of the earth is 8.02 billion people.

Raising Carrying Capacity

To realistically raise the carrying capacity of earth, mankind should optimise their current technologies for producing food, treating and collecting water and distributing land. Since food has been identified as the limiting factor, finding efficient ways to produce more food can raise the carrying capacity. This will require considerations of future global conditions and adjustments to both water and land, which are required to produce food.

FUTURE CONDITIONS

The earth is undergoing rapid changes in climate, environment and resource availability. These changes are expected to accelerate with time and will affect the carrying capacity of earth because they will affect the factors necessary for human life on earth. Some of the most pressing issues are paradoxically driven by the human need for more resources while at the same time limiting the resources available for our future generations.

1. Pollution

- **Plastic**

  The items we consume are deeply flawed in their production and packaging. Many are wrapped or contained in plastic because of its waterproofness but are only used once. The single-use plastics like plastic bags, cutlery and wrappers comprise much of the 4.8-12.7million tonnes [26] of plastic waste that enter our oceans annually. The huge amounts of plastic polluting the earth's waterways and ecosystems contaminates aquatic life which humans eventually consume, thus harming their health, or reject as seafood, thus limiting the amount of edible seafood caught.

- **Greenhouse Gas**
  The energy that powers machinery and manufacturing lines comes from un-renewable sources and harnessing the energy produces toxic emissions like carbon dioxide, mercury, sulfur dioxide and nitrogen oxides — the latter two forming sulfuric and nitric acids when they react with water in the atmosphere. Greenhouse gasses are also emitted from the fuels we use to power our vehicles, which adds carbon monoxide to the atmosphere. The emission of greenhouse gasses is thought to be the single most significant factor that is accelerating the rate of climate change.

2. Climate Change

- **Global Warming**
  The earth is growing warmer every year. This is causing more extreme weather occurrences like floods, hurricanes and storm surges. The warming of the ocean is diminishing the temperature differences between cold and warm waters, thus changing the ocean currents around the world. These currents interact with other phenomena like winds and waves. In already warm regions along the equator, the risk of drought is becoming a lethal reality. Other weather phenomena like polar vortices and tornadoes can occur in previously foreign places because of changing patterns in the movement of warm and cold air.
- **Disease**
  The warming of the earth is prolonging the mating seasons of disease-carrying vectors like mosquitos, ticks and tapeworms. In tropical climates, this increases the risk of malaria, Lyme disease and dengue fever. This lowers the carrying capacity of the earth if populations struggle to reproduce at a rate equal to or greater than the death rate.
- **Ocean Acidification**
  More carbon dioxide in the atmosphere is being absorbed by the oceans. In the water, it can react to form carbonic acid. The acidification of the oceans affects coral reef ecosystems, coastal communities and the aquatic food chains that humans are a part of. Many fish populations may decline due to unfavourable ocean conditions, thus removing a valuable source of food for humans.
- **Melting Ice Reserves**
  The icecaps and glaciers of the world hold approximately 70% of the world's [21] freshwater; however when they melt due to global warming, the water is inseparable from the saltwater from the sea. This loss of freshwater also causes rising sea levels, which decreases the amount of land available for human habitance.

3. Deforestation

The world's forests are being cleared at a rapid rate. While deforestation is driven largely by the need for more space to grow crops and raise livestock, the loss of trees has adverse effects which negate the advantages of more room.

Through photosynthesis, trees absorb carbon dioxide and other greenhouse gasses produced by emissions and expel oxygen as a waste product. The rising amounts of greenhouse gasses in the atmosphere will exacerbate global warming effects. Tree roots play an important part in soil quality, and without them, soil erosion and landslides will become more common which leaves the land arid. The effect of floods will also be worsened due to poor soil quality. Trees also act as wind-breakers and shelter for some communities.

POSSIBLE SOLUTIONS

Due to the effects of the aforementioned future conditions, we are likely to have less habitable land (rising sea level, deforestation,) less sources of food in relation to the population (pests, dry seasons, loss of seafood) and less freshwater in relation to population (pollution, acid rain, droughts.)

Thus, realistic solutions need to use efficient techniques to make the best of the resources we are afforded and increase the amount of food we can produce.

WATER

1. Infrastructure

Water infrastructure is a broad term for systems of water supply, treatment, storage, water resource management, flood prevention and hydropower. Improving the infrastructure around the world can increase the carrying capacity of the earth because it makes available more clean water (for agricultural, industry and household.). This can be done by upgrading our technologies responsible for water treatment and look into ways on how we can use salt water (desalination) as well to have more sources of usable water.

2. Increase Gathering of Freshwater

In places where rainfall is frequent, having personal or communal water tanks or freshwater collection systems can help alleviate the water scarcity around the world. Less of a city's freshwater supply would be used if people collected their own freshwater where possible, thus making more available for irrigation and agriculture.

3. Aquifer Storage and Recovery

Injecting freshwater into underground aquifers for later use is a practical way to prepare for droughts, improve water security and replenish sources of freshwater.

By storing water underground, it can be kept pure from seawater and other contaminants, and drawn up through injection wells later when the demand for freshwater is greater.

4. Water Conservation

In developed cities, where water rushes out of a tap at the twist of a handle, it is hard to imagine a world of water scarcity. But water is finite everywhere. It is important as cities become more populated that people become more mindful about their water consumption and practise turning off running water where possible, re-using dirty water for plants and gardens, and installing water-efficient showerheads and sprinklers.

5. Reducing Pollution

In rivers and lakes that are polluted, a lot of freshwater is deemed unusable because of the contaminants that make it toxic to humans. Reducing pollution on our freshwater ways would make much more water available for use, and/or employing clean-up projects to clean polluted waterways. This process is likely to be labour and money-intensive, but worth it in terms of reclaiming precious water sources.

LAND

1. Reducing Urban Sprawl

When urban areas build low buildings over a large radius, a lot of land mass is wasted to accommodate a relatively low number of people. This is called urban sprawl, and can be combated by building upwards, instead of outwards. This results in more cities with high-rise apartments and skyscrapers that are denser and more space-efficient.

2. Vertical Gardens

The concept of building upwards instead of outwards can also be applied to crops, gardens and farms. Crops growing on walls can save a lot of space, as can growing your own herbs on a vertical plane. This is an efficient solution for crop-growing in cities where there is a lot of available vertical space rather than flat ground. The available flat land can be used to make mass-scale vertical gardens.

3. Farming Less Meat

The space needed to range large livestock animals like cattle, sheep and pigs is immense. It accounts for 38.5% of all inhabitable land. There are many ways the demands for the meat industry can be lessened, thus reducing the amount of meat farms needed and the amount of land required. Simply reducing the meat in one's diet is a viable option for those who do not want to become vegan/vegetarian. Other ways include eating imitation meat which is made from plant-protein, or eating lab-grown meat — which is biologically the same as farmed meat, but obtained through stem cells rather than raising and slaughtering animals.

FOOD

1. Better Energy Sources

Some crops like sugarcane, corn and wheat are grown for the specific purpose of processing, refining and burning to make biofuels [43] like ethanol. Ethanol is an alcohol that is present in many types of fuel and petrol. If the world transitioned from fossil fuels and biofuels to renewable energy like solar, wind and hydropower, the energy crops that would be saved can be used to feed other people.

2. GMO Plants

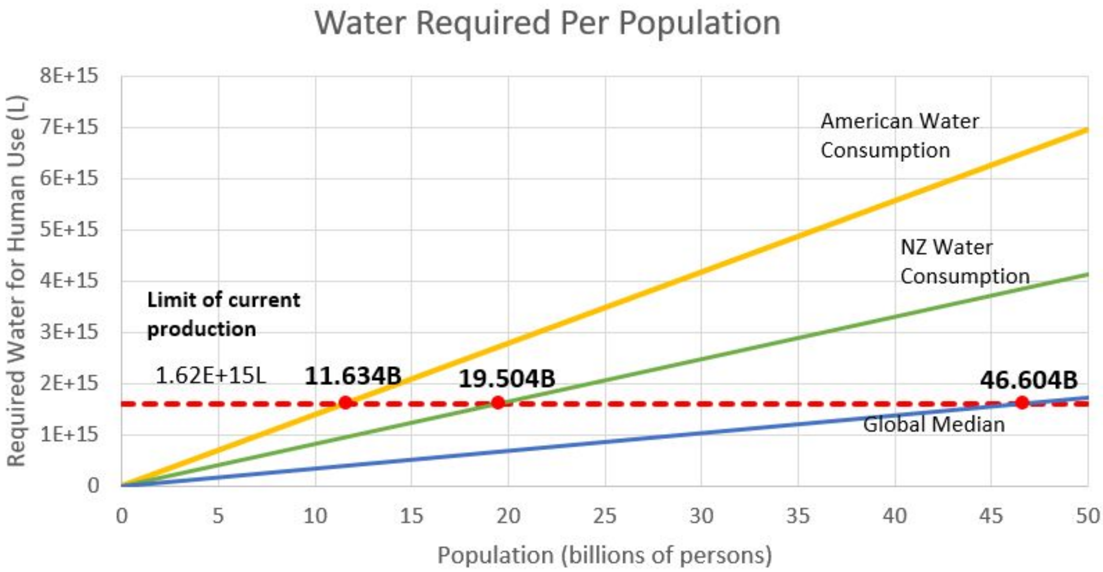
An ideal way to get more food for the same amount of space, sunlight and water is to genetically modify food to produce bigger yields. Genetic modification of crops has already been done many times, notably with Golden Rice, [44] a strain of rice that has more beta-carotene for people in developing countries with Vitamin A deficiencies. The same technology could be employed to prolong harvest seasons, obtain larger fruits or vegetables with a longer shelf life that allow them to be transported for longer.

3. Stop Food Waste

In many developed countries, issues like food scarcity can be easily combated by simply reducing food waste. Globally, one third of the food we produce is wasted — 1.3 billion tonnes. [35] This waste happens at all steps of the food production chain, from farms to consumers. Food is thrown away because of size, cosmetic imperfections and ‘abnormalities’ that don’t affect its edibility at all. Supermarkets throw away food that is nearing but not past its best before date (which contrasts with the use-by date) and in households food that is leftover is often disposed of. All these losses are wasting the resources that went into producing that food, but also placing more strain on the agriculture industry to make more food to replace it.

Forecasted Models

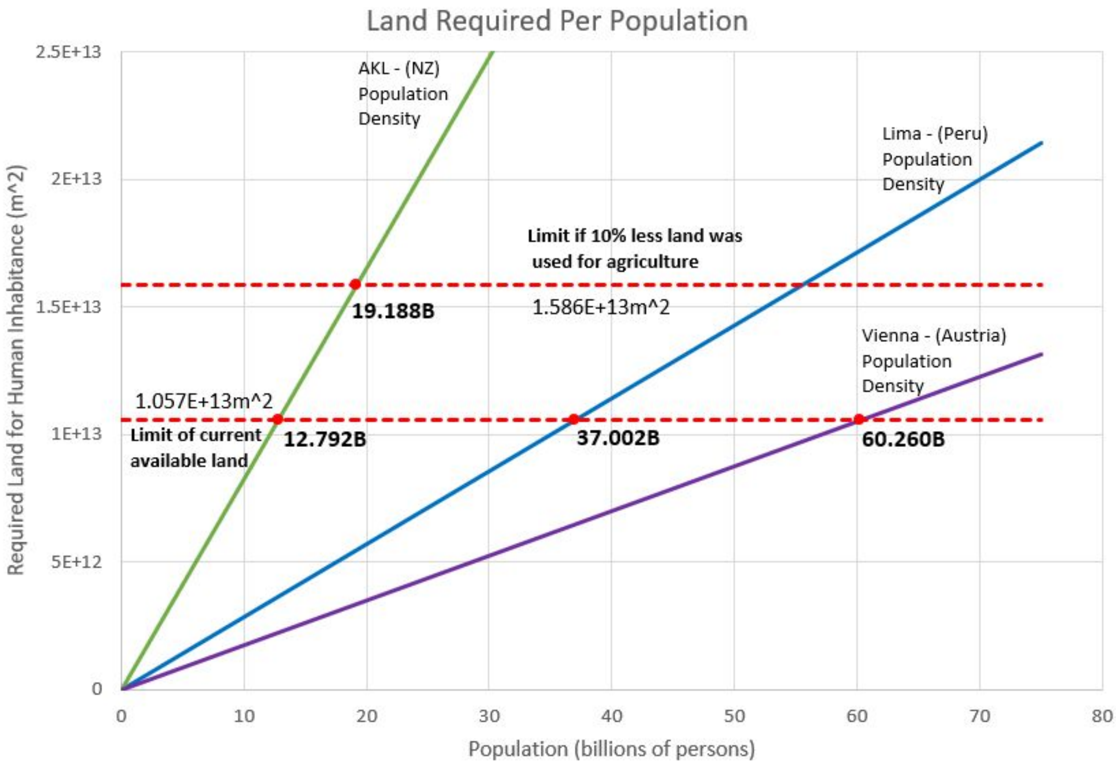
WATER



Better Use of Existing Freshwater

We have not modelled a forecast for water consumption in future scenarios. Above is the water general model. This is because this model was made under the assumption that maximum freshwater is collected and treated from the sources available under today's conditions and technology. This assumption is indeed false, because through treatment capacity and wastage, there is less freshwater than 1.62E+15 litres available to the population. Even in the cases where it is available, i.e. in lakes and reservoirs, problems with access, filtering and treatment result in 2.1 billion [41] people worldwide without access to sanitary water — like in Flint, Michigan. Thus, to achieve the ideal carrying capacity assuming a rate of water consumption at New Zealand standards, more work of infrastructure and treatment needs to be done to get to the 1.62E+15 litres of freshwater that we assumed was available.

LAND



On this model for forecasted available land for human habitance, we can see the potential effect of certain changes to the limit of available land. There are two red lines which represent the limits of land availability for different scenarios. The bottom-most line is how much land is available for habitance today, obtained from the general model for land.

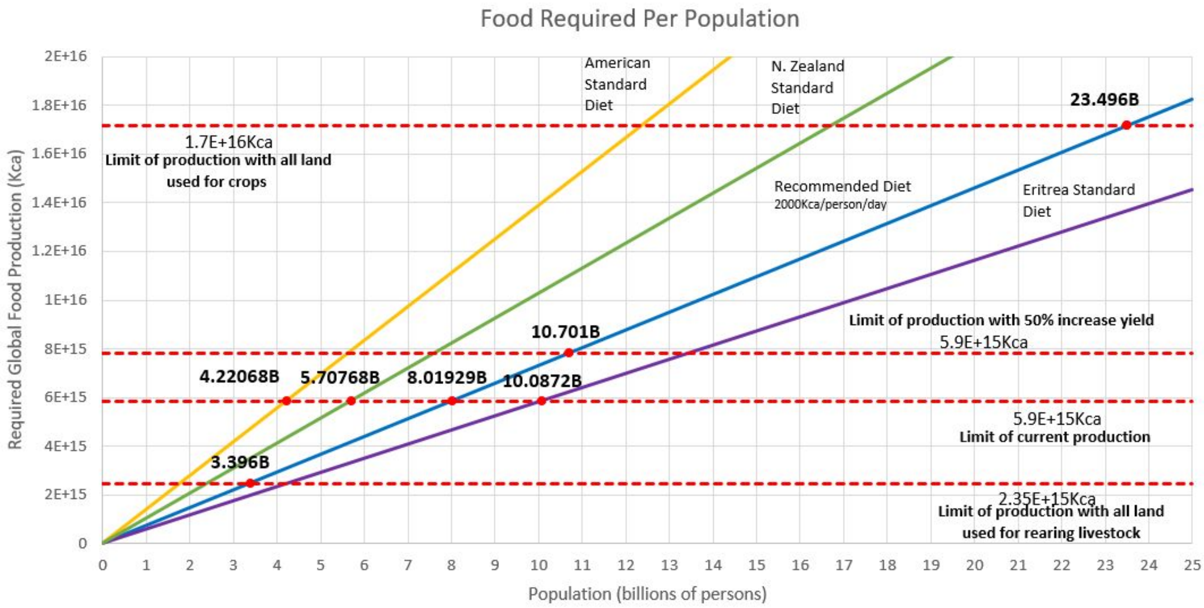
Repurposing Agricultural Land

Agricultural land takes up more room than all the humans on earth. The vast farms and ranches we require to raise livestock and grow crops takes up a huge amount of the habitable land on earth. One solution to getting more land would be to cut down more forests, but that would result in even more adverse effects for the environment and future generations. Thus, the most realistic solution for increasing the land available for habitance would be to repurpose the land humans have already cleared away. By eating less meat, the demand for livestock would be decreased and the land previously required to range them can be used instead for human settlements. By also using vertical gardens, which allow multiples of existing crop yields to be grown in the same amount of surface land area, agricultural land can be repurposed for human settlement. Assuming a population with the density of Auckland in the urban areas of the earth, the size of which would increase by 10%, the carrying capacity of the earth can be increased from 12.8 billion to 19.2 billion.

Urban Living

Clearly, having more people living in one place saves space. This can be seen by looking at the population density lines of Lima and Vienna. We were unable to calculate the average density of the world since not all habitable land is actually inhabited. But a viable solution in raising the limit of available land would be to continue developing suburbs, towns and small villages into more urban cities as more people need places to live.

FOOD



On this model for forecasted productions of food, we can see the potential effect of certain lifestyle changes to the limit of production. There are four red lines which represent the limits of food production for different scenarios. The second bottom-most line is the limit of current production today, used from the general model for water.

Eating Less Meat

The top-most red line is the limit of food production if the majority of the world adopted vegetarian/vegan diets, thus eliminating the need for livestock land. This agricultural land can be used to grow more crops. Not only are plants easier to grow with the same amount of land and water, they convert these resources into more protein than meat would. The crops like corn and wheat that we feed to livestock are converted into less meat protein than the plant protein they began with. Thus by adopting less meat-heavy diets, the capabilities to produce more food increase dramatically. Assuming the population consumes the recommended amount of calories per day, adopting plant-based diets could increase the carrying capacity from 8.02 billion people to 23.5 billion people. Conversely, if meat consumption increases to the point where all agricultural land is used for rearing livestock, the carrying capacity will decrease to 3.4 billion people.

While we acknowledge that fully carnivorous and fully herbivorous diets are both unlikely considering the wide scope of religious and cultural lifestyles in the world, having a largely plant-based diet with as little as meat as possible has positive outcomes for the carrying capacity of the earth.

Genetically Modified Agriculture

The second top-most red line forecasts the effect of using genetically modified crops and animals in agriculture. Genetically modifying crops to grow bigger can increase yields by 50%. [40] Genetically modifying farm animals has been done, but to a less widespread extent across the farms of the world. However, there is no biological reason the same genetic engineering cannot be applied everywhere to yield larger animals with even more favourable meat to fat ratios to get more protein in each animal. This limit assumes that genetically modified organism comprise a majority of the agriculture industry, thereby raising the limits of food production by 50%. If everyone consumes only the recommended amount of calories per year, the carrying capacity of earth can be increased from 8.02 billion to 10.7 billion.

Inequality

There are many assumptions that we have made in our forecasted models for the purposes of making calculations. We have taken the averages of resource consumption, and in making predictions, assumed that increases in food efficiency, or available land will be accessible to every member of the global population.

However, this is not the case in reality. Our figure of 8.02 billion people as the current carrying capacity has been calculated assuming every person eats 2,000 calories a day — the recommended amount for a healthy human adult. However, looking at current growth rates, this number will easily be surpassed within five-ten years. This simply means that earth has a higher carrying capacity when we afford each person of the population less resources than what is healthy, recommended or fair.

Even today, there are approximately 783 million people living in extreme poverty, [39] not accounting for those in slight poverty. It is highly likely that their caloric consumption would be far less lower than the recommended, with the result that many people will die as a result of starvation and malnourishment even though the growth rate of these regions is still positive. Other places are severely overpopulated with tens of people sharing a small house, and other places are suffering droughts and water scarcity.

Therefore, in our forecasted models where production of food and water are increased, it is of greater importance to ensure a more equal and fair distribution of these resources among the existing populations, than trying to drive production up with no thought to creating a more equitable world. Human populations can be sustained indefinitely on scraps of food, small amounts of filthy water and practically no living space at all so long as children are still created — and while this fits with the ecological definition of carrying capacity, it is not ethical to allow such poverty to continue. That is why we would also recommend water infrastructure, medical aid, education and work opportunities be brought to developing countries as a reparative measure.

Strengths and Weaknesses

STRENGTHS	WEAKNESSES
● We have modelled three important factors to human life. ● We have accounted for different ways of life and their effect of resource consumption. ● Considerations have been given to future conditions and their effect on the available resources. ● We have brainstormed realistic solutions to improve the carrying capacity of the earth. ● We have modelled the effect of the realistic solutions. ● Our modelled carrying capacity (8.02-10.7 billion people with food as a limiting factor) aligns with other studies done. [45]	● We haven't analysed the effect of one resource on another. ● We haven't analysed quality of life factors like healthcare and sanitisation. ● Many assumptions had to be made due to lack of/unclear data about water, land and food.

Appendices

WATER MODEL

American Consumption	TotalWater(L)	1.26E+21	cit. 20
	FreshWater(L)	3.15E+19	cit. 21
	SurfaceWater(L)	3.78E+17	cit. 21
	RiversAndLakes(L)	8.0854E+16	cit. 21
	UsableWaterRiversAndLakes(L)	1.6171E+16	cit. 21
	WaterUsedForHumanUse(L)	1.6171E+15	cit. 22
	WaterUsePerPersonPerDay (L)	380.541	cit. 23
	WaterUsePerPersonPerYear (L)	138992.6	
	Carrying Capacity (persons)	1.1634E+10	
	Carrying Capacity (billions of persons)	11.6343172	
NZ Consumption	WaterUsePerPersonPerDay (L)	227	cit. 24
	WaterUsePerPersonPerYear (L)	82911.75	
	Carrying Capacity (persons)	1.9504E+10	
	Carrying Capacity (billions of persons)	19.5036771	
Global Median Consumption	WaterUsePerPersonPerDay (L)	95	cit. 25
	WaterUsePerPersonPerYear (L)	34698.75	
	Carrying Capacity (persons)	4.6604E+10	
	Carrying Capacity (billions of persons)	46.6035232	

LAND MODEL

LIMA	Total Land (m^2)	1.489E+14	cit. 1
	Inhabited Land (m^2)	1.05719E+13	cit. 15, cit. 16
	Population Density (km^-2)	3500.00	cit. 17
	Population Density (people/m^-2)	0.0035	
	Area required per person (m^2)	285.7142857	
	Carrying Capacity (persons)	37001650000	
	Carrying Capacity (billions of persons)	37.00165	
AUCKLAND	Population Density (km^-2)	1210.00	cit. 18
	Population Density (people/m^-2)	0.00121	
	Area required per person (m^2)	826.446281	
	Carrying Capacity (persons)	12791999000	
	Carrying Capacity (billions of persons)	12.791999	
VIENNA	Population Density (km^-2)	5,700	cit. 19
	Population Density (people/m^-2)	0.0057	
	Area required per person (m^2)	175.4385965	
	Carrying Capacity (persons)	60259830000	
	Carrying Capacity (billions of persons)	60.25983	
10% less agriculture land	Inhabited Land (m^2)	1.58579E+13	
	Area required per person (m^2)	826.446281	
	Carrying Capacity (persons)	19187998500	
	Carrying Capacity (billions of persons)	19.1879985	

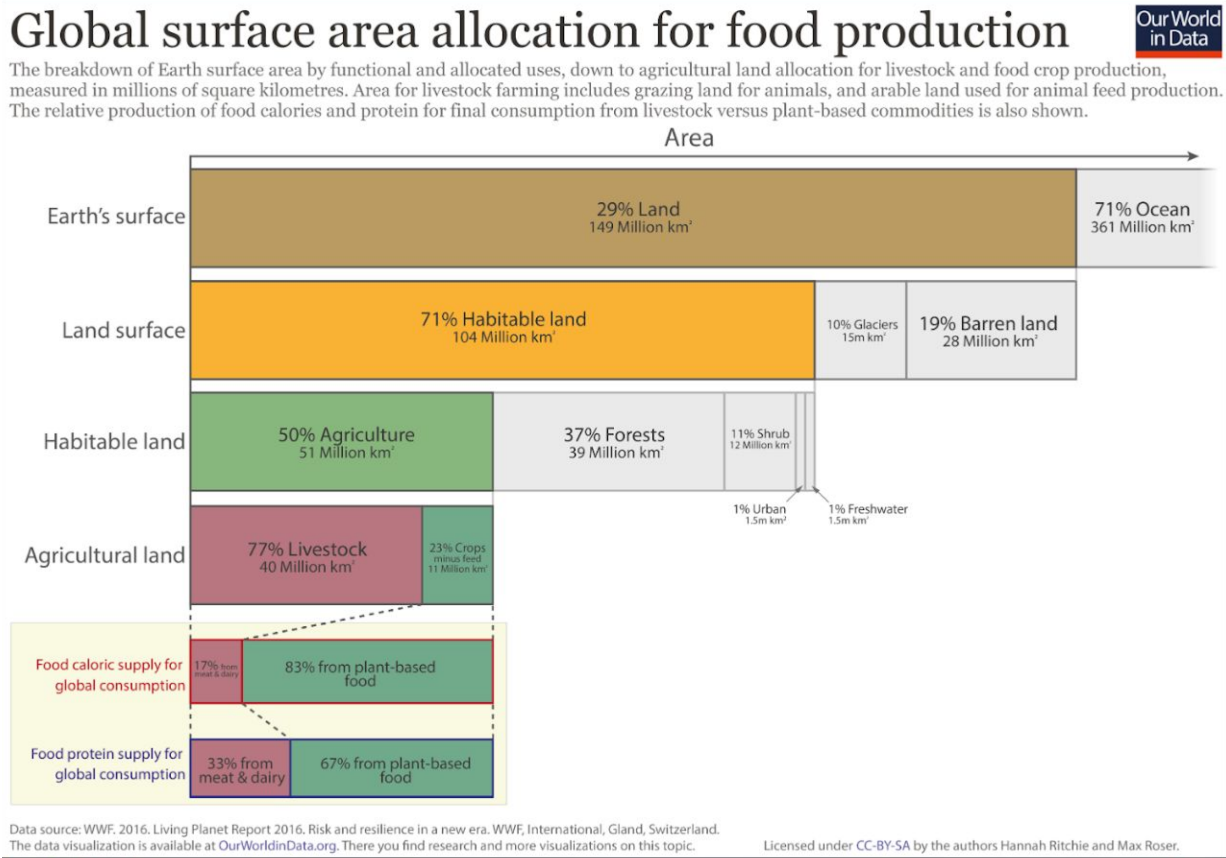
FOOD MODEL

Recommended Diet	Total Land (m^2)	1.49E+14	cit. 1
	Used Agricultural Land (m^-2)	5.29E+13	cit. 2
	Usable Agricultural Land (m^-2)	1.47E+14	cit. 3
	Usable Protein for Meat (m^-2)	4	cit. 4
	Usable Protein for Soybeans (m^-2)	29	cit. 4
	Percentage of Agricultural Land used for meat (%)	77	cit. 5
	Percentage of Agricultural Land used for plants (%)	23	cit. 5
	Average usable protein for land-based food (m^-2)	9.75	
	Average usable calories for land-based food (Kcam^-2)	39	cit. 6
	Total land-based food produced (Kca)	5.73E+15	
	Seafood produced global (tonnes)	1.44E+08	cit. 7
	Seafood produced global (grams)	1.44E+14	
	Usable seafood global (grams)	1.29E+14	cit. 8
	Calories from seafood global (Kca)	1.32E+14	cit. 9
	Total food produced (Kca)	5.86E+15	
	Calories intake per person per day (Kca)	2000	cit. 10
	Calories intake per person per year (Kca)	730500	
	Carrying Capacity (persons)	8.02E+09	
	Carrying Capacity (billions of persons)	8.01929	
American	Calories intake per American person per day (Kca)	3800	cit. 11
	Calories intake per American person per year (Kca)	1387950	
	Carrying Capacity (persons)	4.22E+09	
	Carrying Capacity (billions of persons)	4.220679	
Eritrea	Calories intake per Eritrea person per day (Kca)	1590	cit. 12
	Calories intake per Eritrea person per year (Kca)	580747.5	
	Carrying Capacity (persons)	1.01E+10	
	Carrying Capacity (billions of persons)	10.08716	
N.Z.	Calories intake per NZ person per day (Kca)	2810	cit. 13
	Calories intake per NZ person per year (Kca)	1026353	
	Carrying Capacity (persons)	5.71E+09	
	Carrying Capacity (billions of persons)	5.70768	

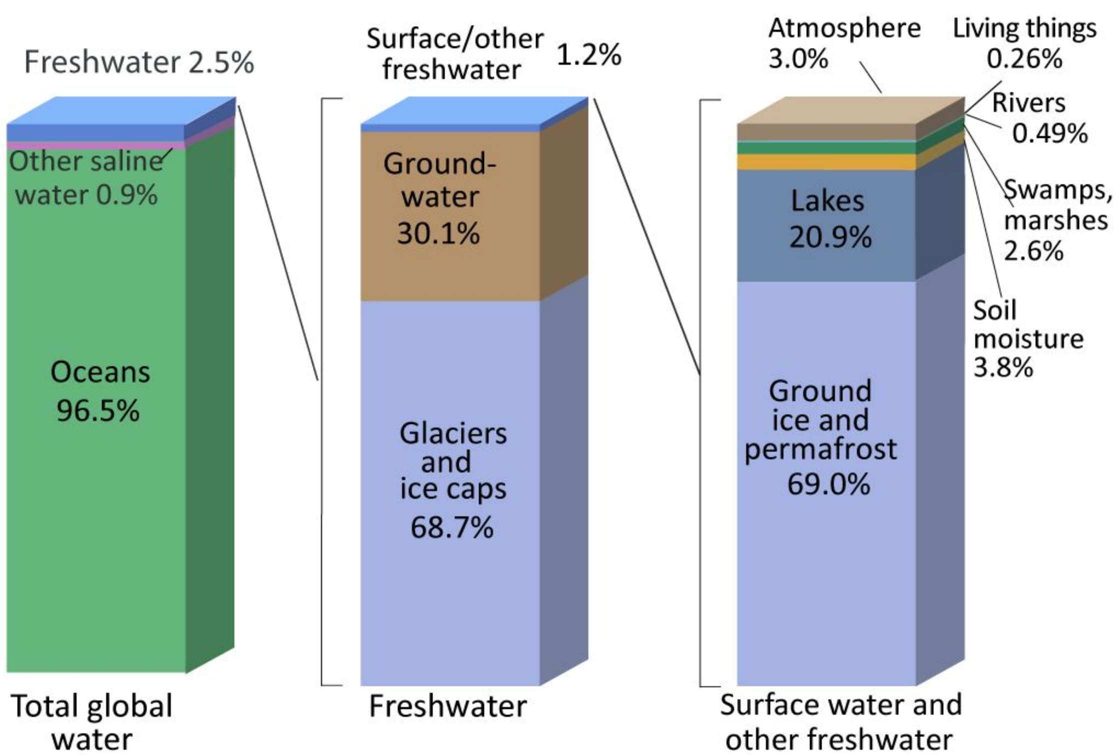
ONLY MEAT	Average usable protein for land-based food (m^-2)	4	
	Average usable calories for land-based food (Kcam^-2)	16	
	Total land-based food produced (Kca)	2.35E+15	
	Calories from seafood global (Kca)	1.32E+14	
	Total food produced (Kca)	2.48E+15	
	Calories intake per person per year (Kca)	730500	
	Carrying Capacity (persons)	3.4E+09	
	Carrying Capacity (billions of persons)	3.396245	
ONLY CROPS	Average usable protein for land-based food (m^-2)	29	
	Average usable calories for land-based food (Kcam^-2)	116	
	Total land-based food produced (Kca)	1.7E+16	
	Calories from seafood global (Kca)	1.32E+14	
	Total food produced (Kca)	1.72E+16	
	Calories intake per person per year (Kca)	730500	
	Carrying Capacity (persons)	2.35E+10	
	Carrying Capacity (billions of persons)	23.49644	
GMO TO INCREASE YIELD	Usable Protein for Meat (m^-2)	4	
	Usable Protein for Soybeans (m^-2)	43.5	cit. 14
	Percentage of Agricultural Land used for meat (%)	77	
	Percentage of Agricultural Land used for plants (%)	23	
	Average usable protein for land-based food (m^-2)	13.085	
	Average usable calories for land-based food (Kcam^-2)	52.34	
	Total land-based food produced (Kca)	7.69E+15	
	Calories from seafood global (Kca)	1.32E+14	
	Total food produced (Kca)	7.82E+15	
	Calories intake per person per year (Kca)	730500	
	Carrying Capacity (persons)	1.07E+10	
	Carrying Capacity (billions of persons)	10.70066	

Water source	**Water volume, in cubic miles**	**Water volume, in cubic kilometers**	**Percent of freshwater**	**Percent of total water**
Oceans, Seas, & Bays	321,000,000	1,338,000,000	--	96.54
Ice caps, Glaciers, & Permanent Snow	5,773,000	24,064,000	68.7	1.74

Groundwater	5,614,000	23,400,000	--	1.69
Fresh	*2,526,000*	*10,530,000*	*30.1*	*0.76*
Saline	*3,088,000*	*12,870,000*	--	*0.93*
Soil Moisture	3,959	16,500	0.05	0.001
Ground Ice & Permafrost	71,970	300,000	0.86	0.022
Lakes	42,320	176,400	--	0.013
Fresh	*21,830*	*91,000*	*0.26*	*0.007*
Saline	*20,490*	*85,400*	--	*0.006*
Atmosphere	3,095	12,900	0.04	0.001
Swamp Water	2,752	11,470	0.03	0.0008
Rivers	509	2,120	0.006	0.0002
Biological Water	269	1,120	0.003	0.0001



Where is Earth's Water?



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