Accenture / Fjord   Dublin (via teleconference)   21 July 2020

Systems Theory in Design

Systems Dynamics

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So far, we've looked at systems as elements + relationships.
And we've looked at relationships-as-rules (as in design systems)
and also at relationships-as-structure (as in networks).

Last week we began to talk about communication,
information flowing through a system.

Next, we distinguish explicitly between static and dynamic systems.

**A static system remains the same,
until the rules of the system change.
It has only one state.**

**A dynamic system may change,
within the rules of the system.
It has a range of possible states.**

**A dynamic system maintains itself —
it maintains the set of relationships that are the system —
even while "stocks" flow through the structure.**

Key terms in systems dynamics:

- Stock
- Flow
- Source
- Sink
- Lag
- Equilibrium

"A stock is the foundation of any system. ...
the elements ... you can see, feel, count, or measure at any given time.

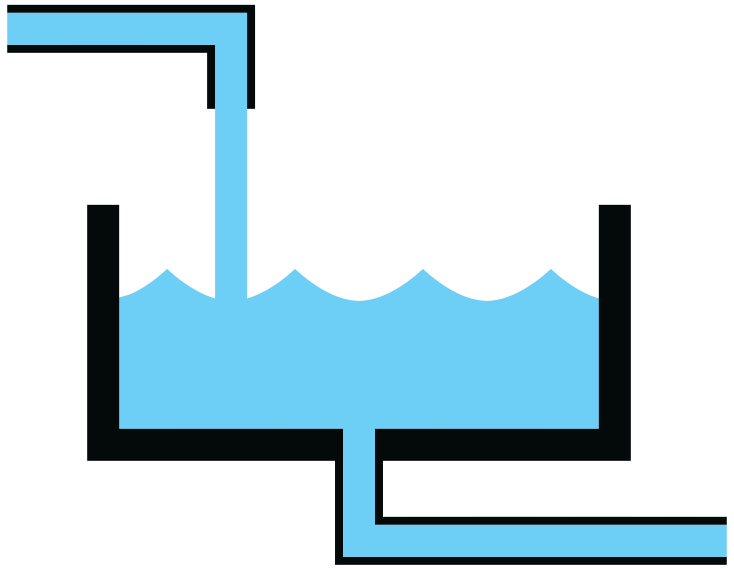
... an accumulation of material or information that has built up over time.
It may be the water in a bathtub, a population, the books in a bookstore,
the wood in a tree, the money in a bank, your own self-confidence.
A stock does not have to be physical. Your reserve of good will toward others
or your supply of hope that the world can be better are both stocks."

— Donella Meadows

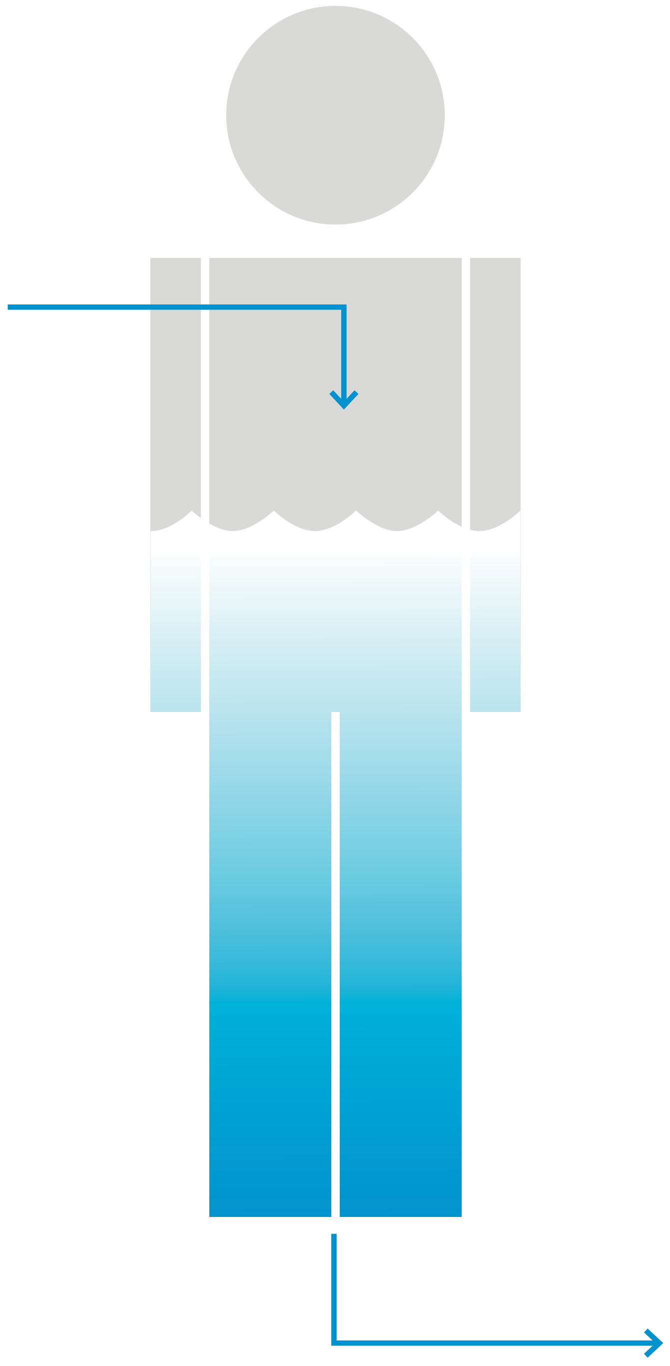
“Stocks change over time through the actions of a flow.

Flows are filling and draining, births and deaths, purchases and sales,
growth and decay, deposits and withdrawals, successes and failures.
A stock, then, is the present memory of the history of changing flows within the system.”

— Donella Meadows



Living systems must maintain dynamic equilibrium to survive.



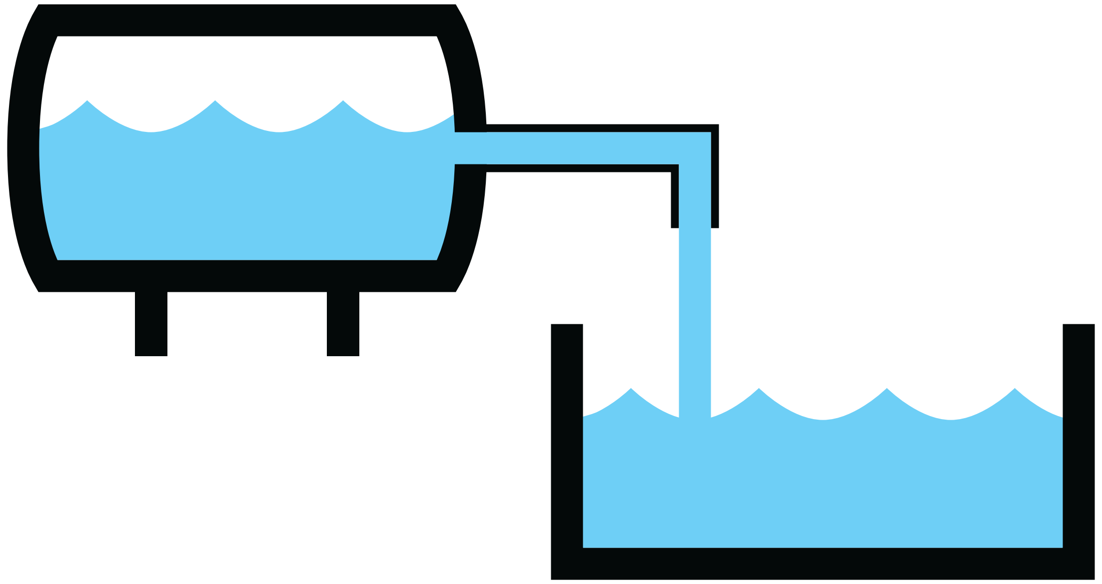
Fuel flows through engines

Dissipative systems, e.g., a standing wave or whirlpool

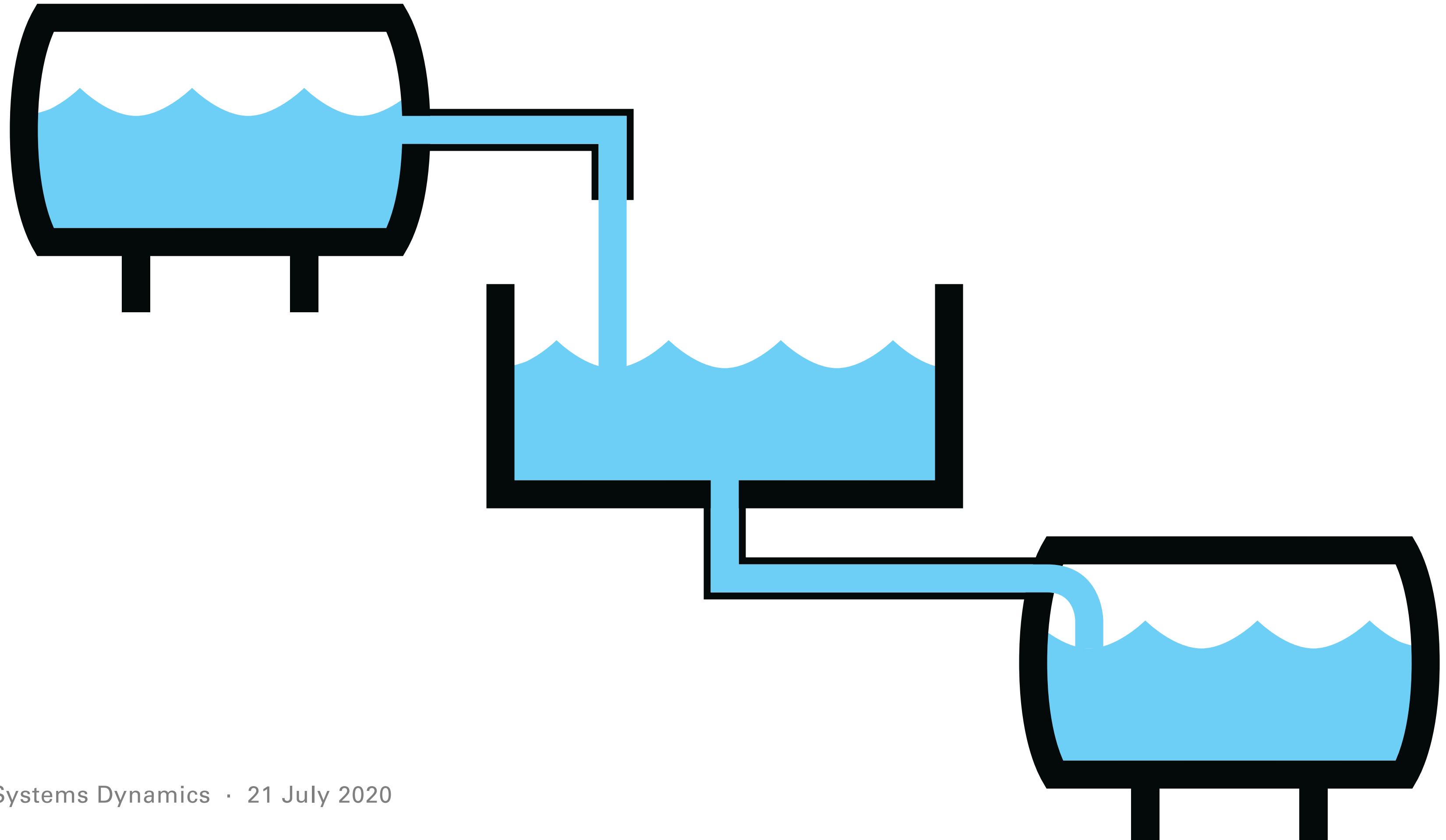
A whirlwind or tornado

A cyclone or hurricane

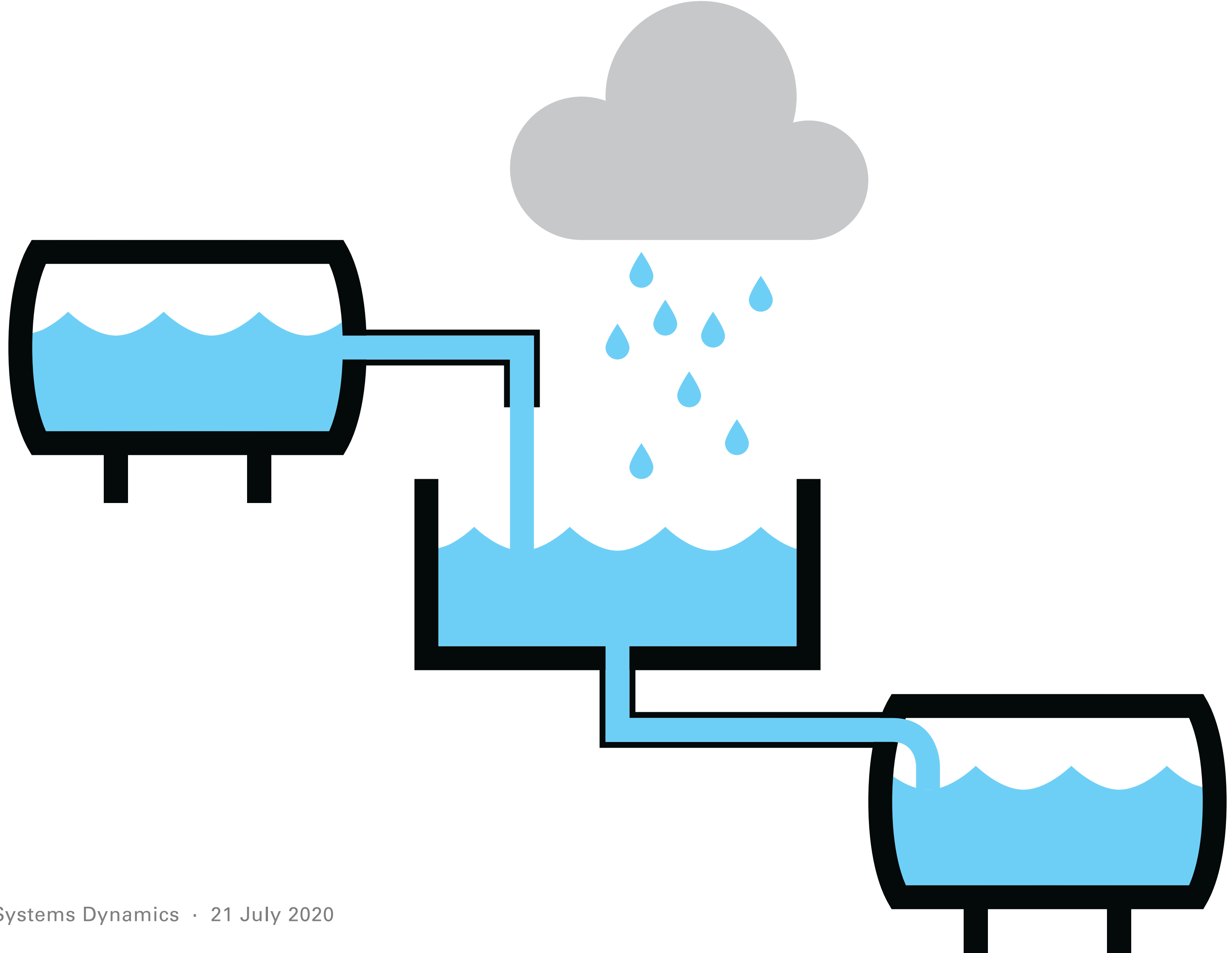
Water flows in from a source.



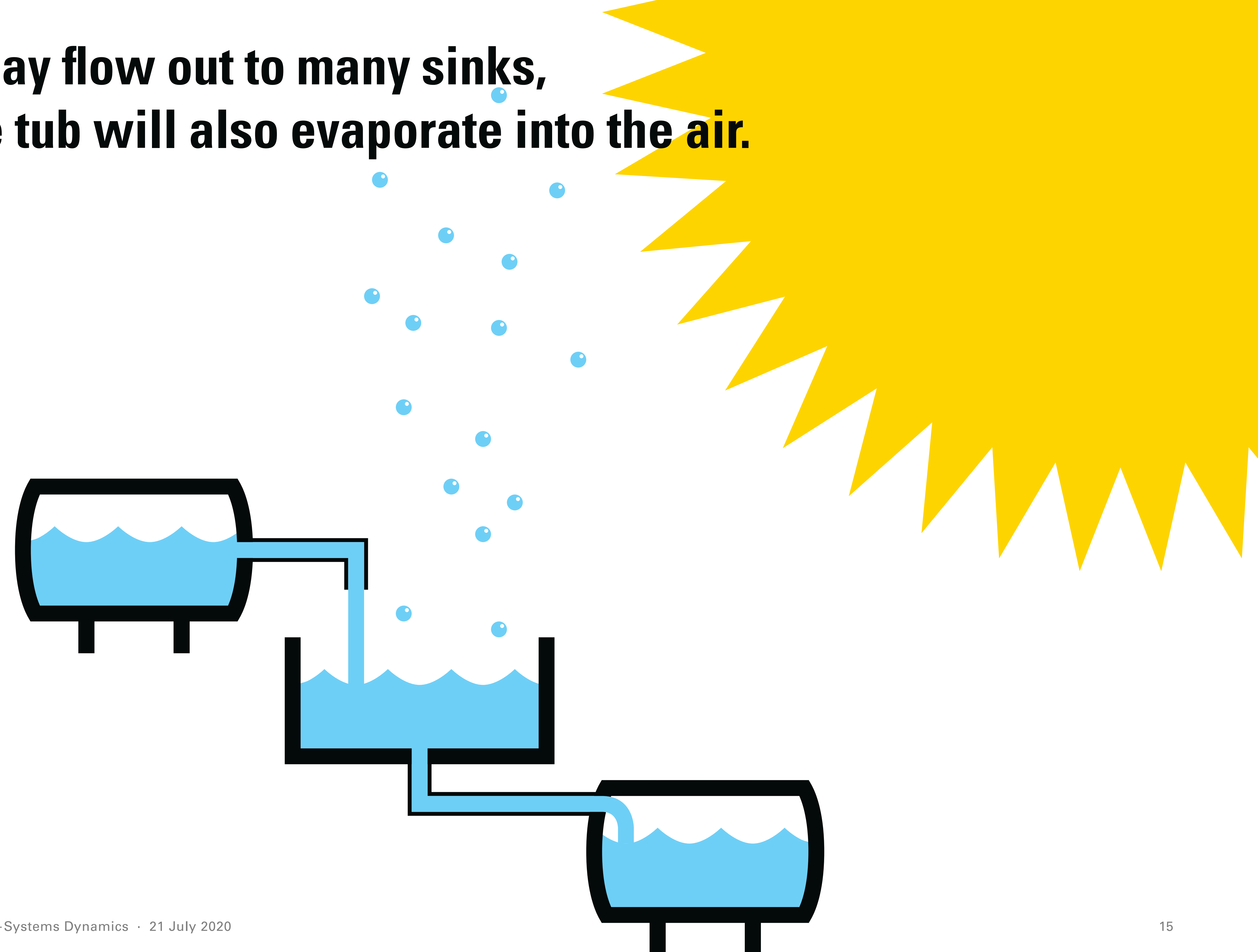
Water may also flow out to a sink.



Many sources may flow into one stock, e.g., if the tub is outside, rain may also fall into it.

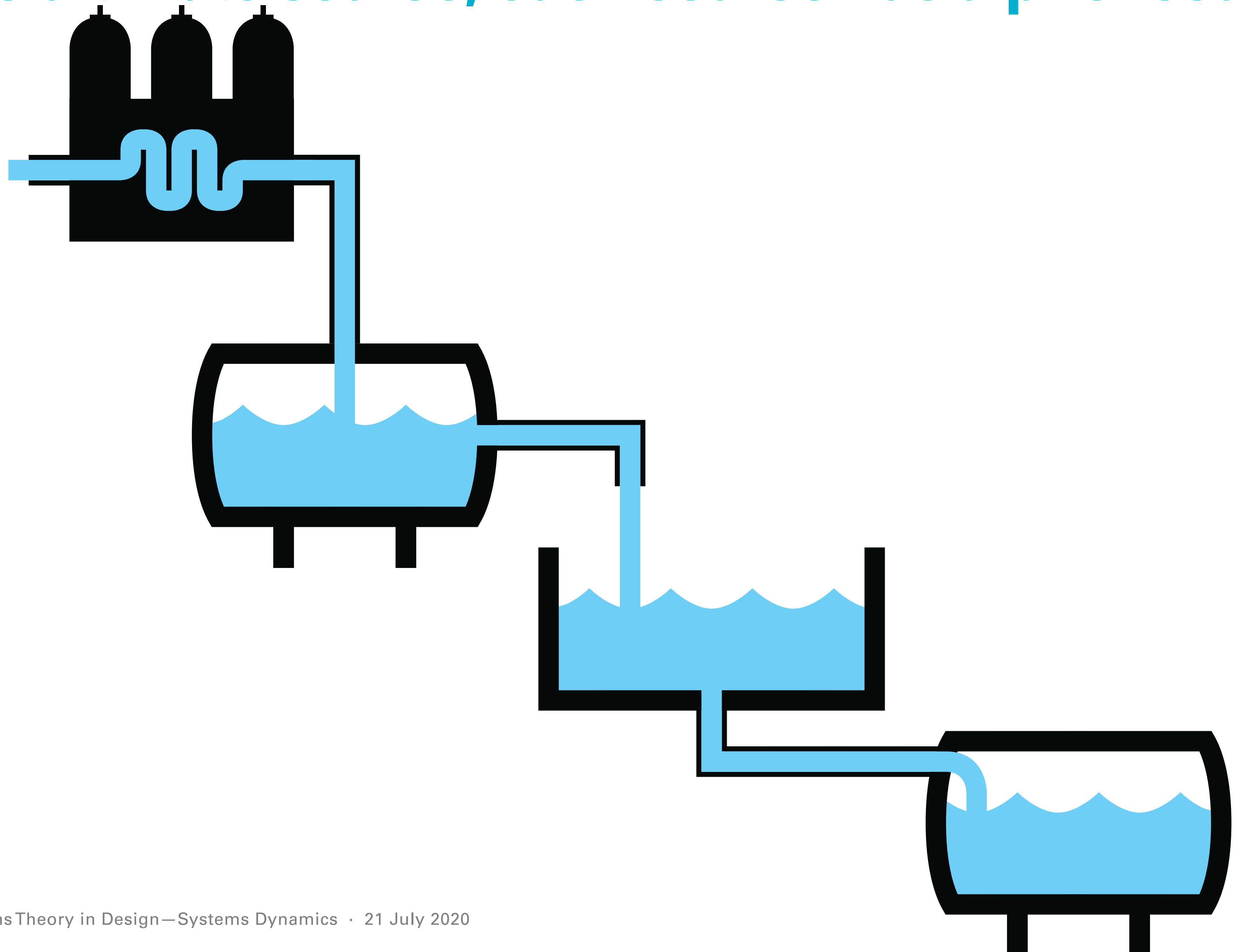


And one stock may flow out to many sinks, e.g., water in the tub will also evaporate into the air.



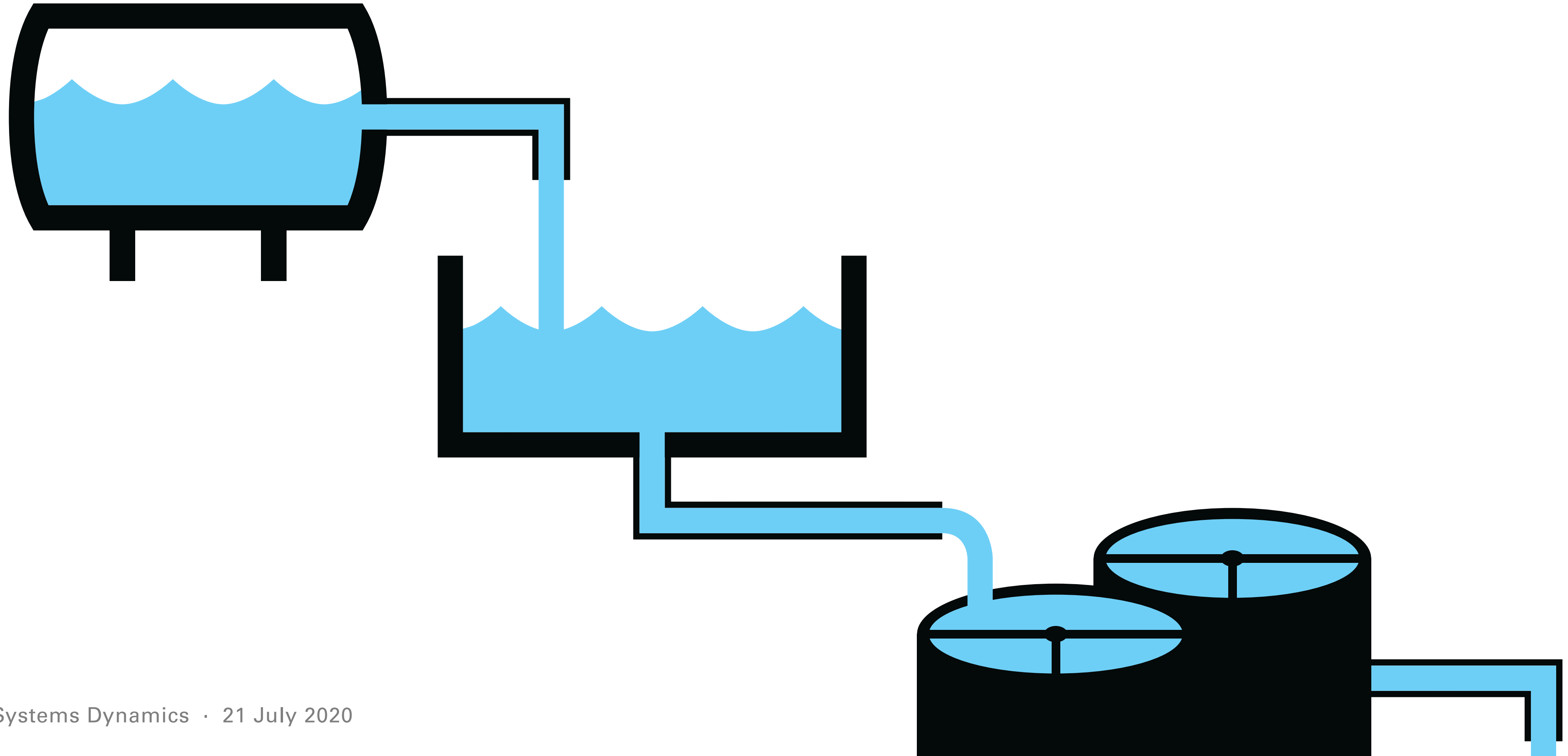
The main source may be a tank, which itself has a prior source, perhaps a water filtering plant.

There is no ultimate source; each source has a prior source.



The main sink may be a sewer system, which itself has a subsequent sink, perhaps a sewer water filtering plant.

There is no ultimate sink; each sink has a subsequent sink.

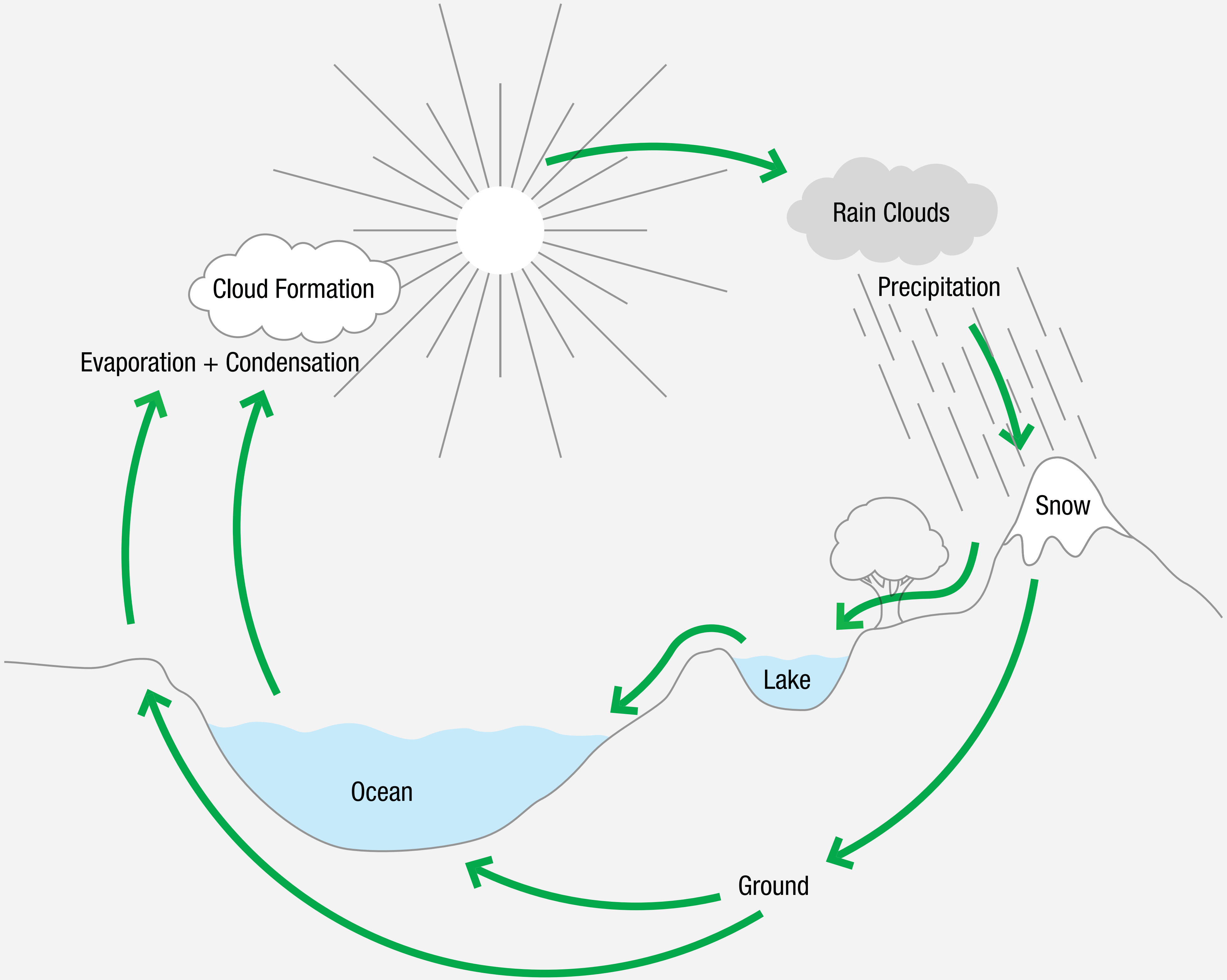


One person's source may be another person's sink.

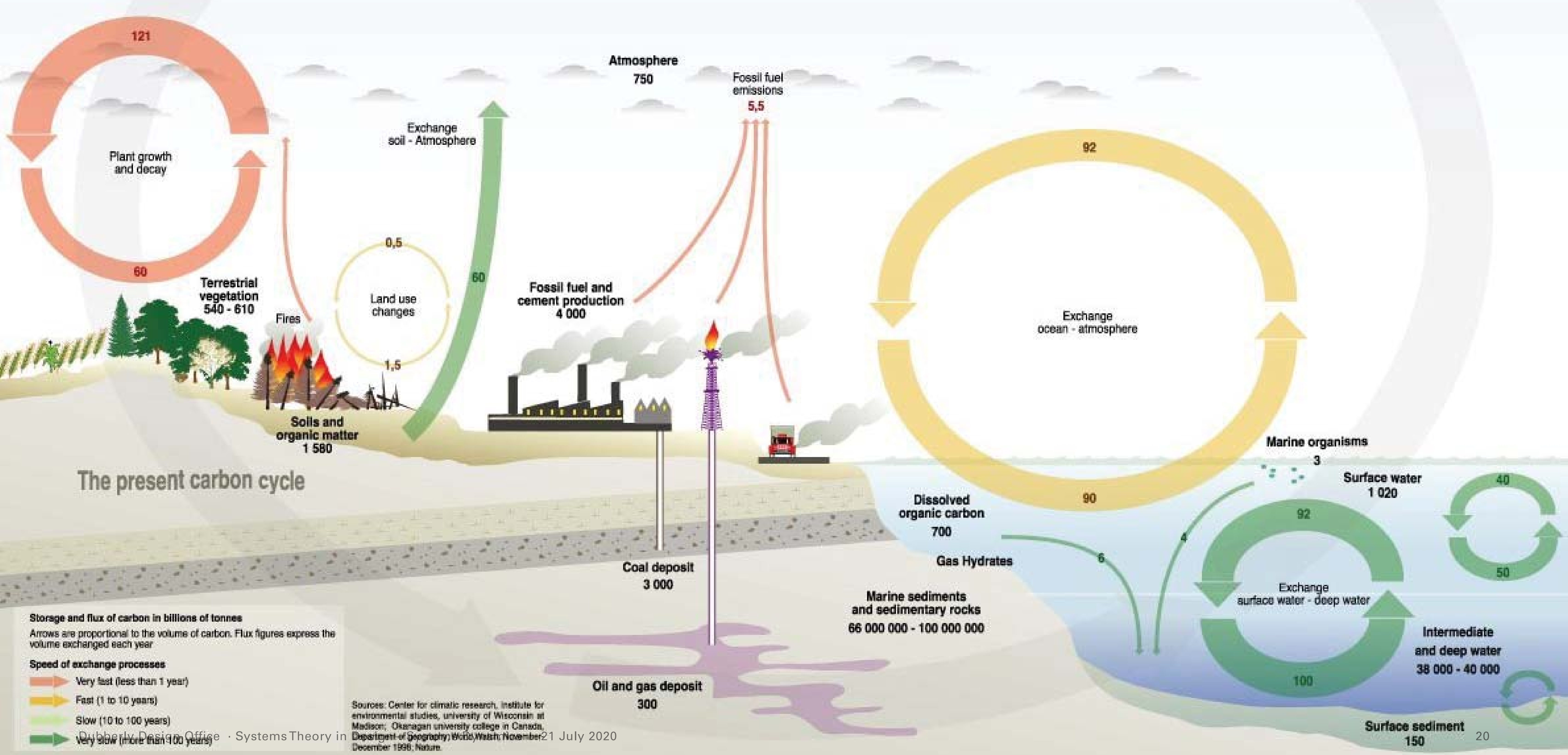
People in Amsterdam get much of their water from the Rhine; people upstream in Basel, discharge their treated sewer water into the Rhine.

Along the way, a drop of water may travel through the cycle several times.

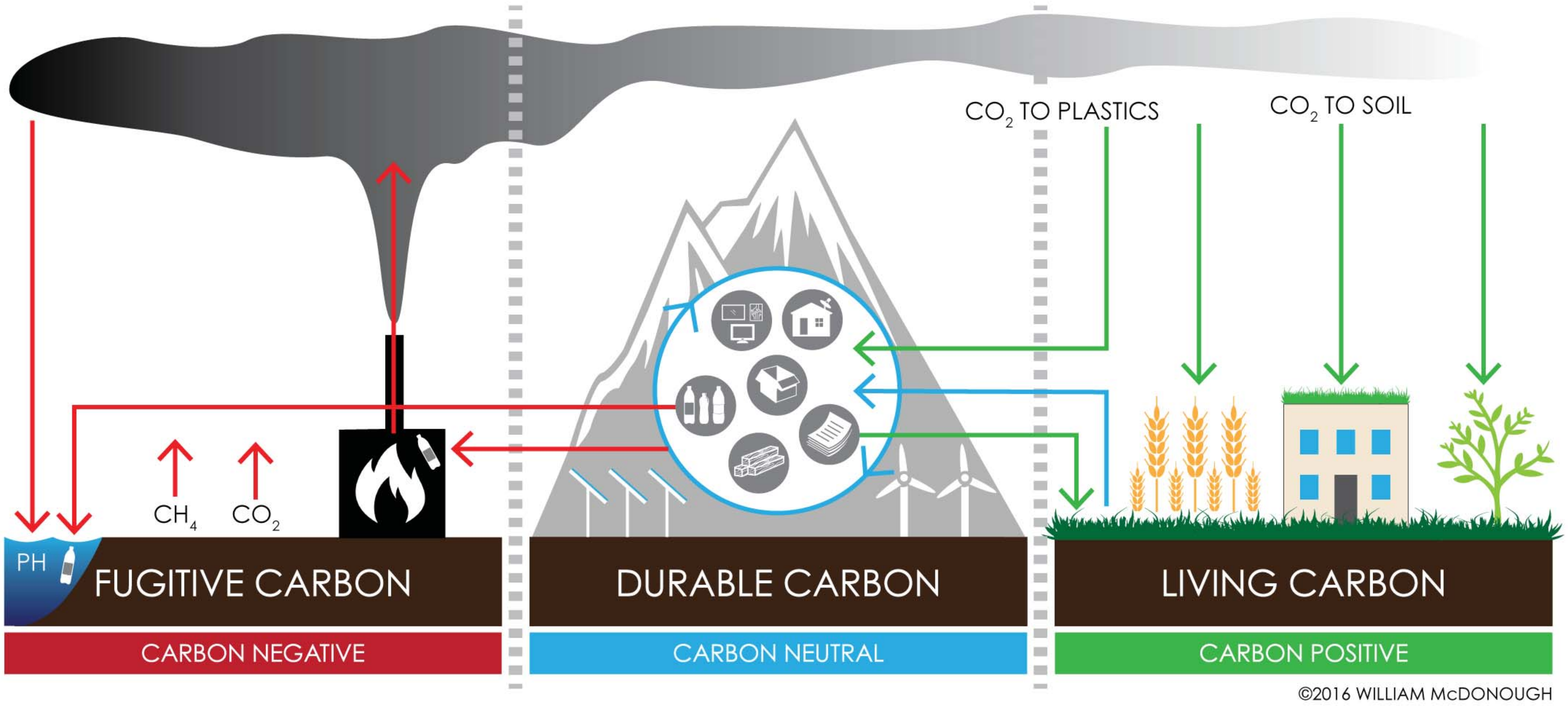
Water travels continuously through a cycle.



Carbon also travels through a cycle.



The new language of carbon



The new language of carbon

Too much carbon in the atmosphere is damaging. Instead, it should be retained in durable forms such as plastic and wood or in living organisms. Recycling materials and nurturing the soil ensure that carbon ends up in the right places in the right amounts.

FUGITIVE CARBON

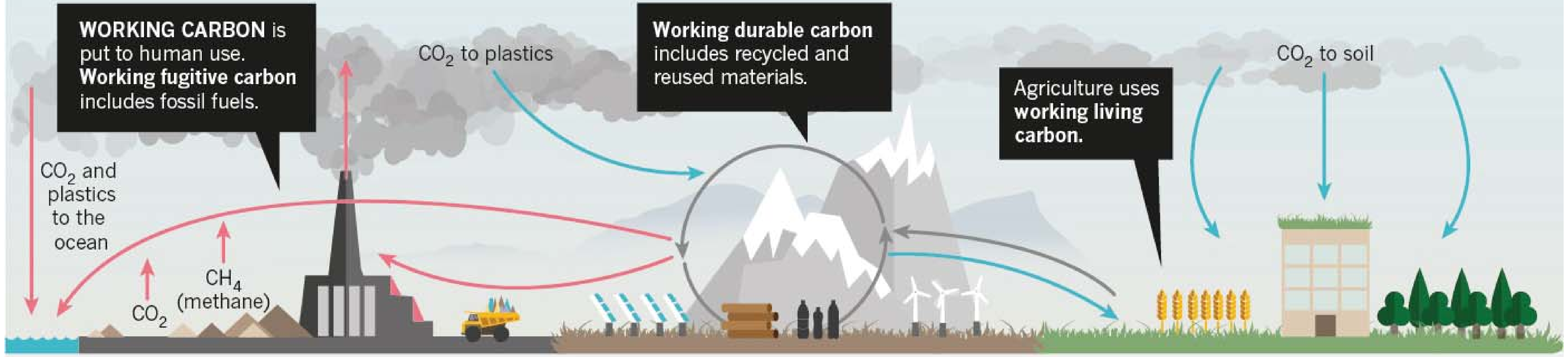
Has ended up somewhere unwanted and can be toxic. It includes carbon dioxide released into the atmosphere by burning fossil fuels, 'waste to energy' plants, methane leaks, deforestation, much industrial agriculture and urban development. Plastic in the ocean is fugitive carbon.

DURABLE CARBON

Locked in stable solids such as coal and limestone, or in recyclable polymers that are used and reused. It ranges from reusable fibre, such as paper and cloth, to building and infrastructure elements that can last for generations and then be reused.

LIVING CARBON

Organic, flowing in biological cycles, providing fresh food, healthy forests and fertile soil. It is something we want to cultivate and grow. Soil includes living carbon in the form of fungi, microbes, humus, legumes and grasses.



MANAGEMENT STRATEGIES

CARBON NEGATIVE

Actions that pollute the land, water and atmosphere with various forms of carbon. For example, releasing methane into the atmosphere or plastic waste into the ocean is carbon negative.

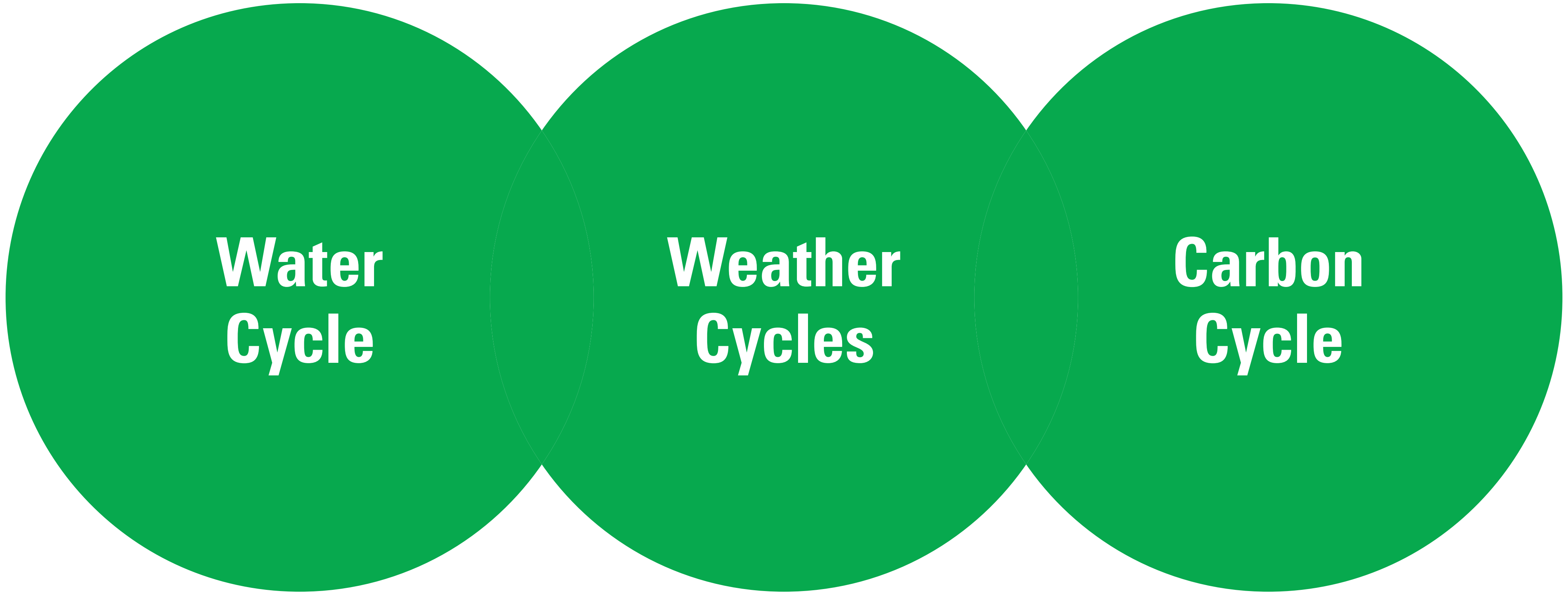
CARBON NEUTRAL

Actions that transform or maintain carbon in durable earthbound forms and cycles for use across generations; or renewable energy such as solar, wind and hydropower that do not release carbon.

CARBON POSITIVE

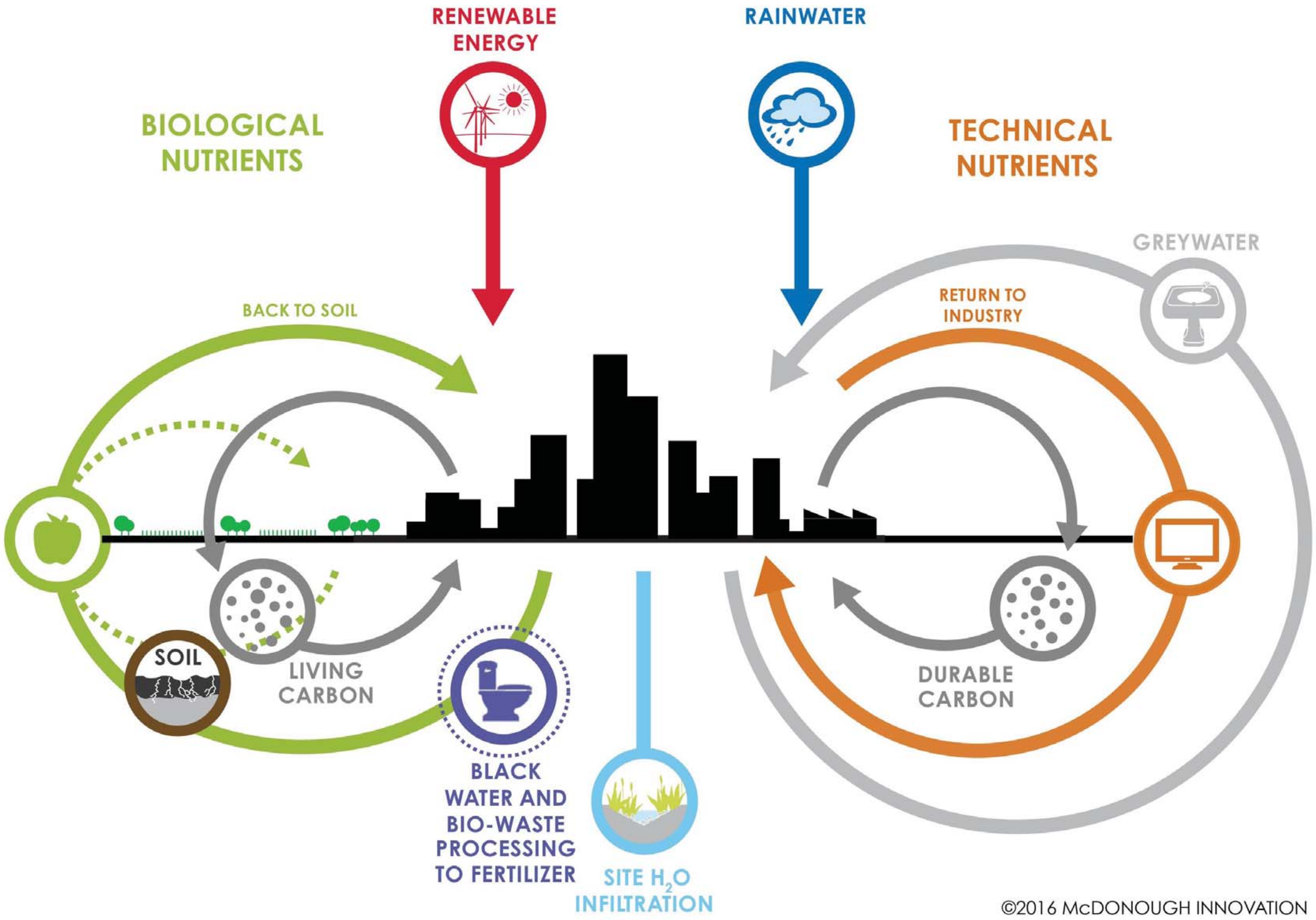
Actions that convert atmospheric carbon to forms that enhance soil nutrition or to durable forms such as polymers and solid aggregates. Also includes the recycling of carbon into soil nutrients from organic materials, food waste, compostable polymers and sewage.

**Sometimes large quantities can be tied up—
sequestered—
so that they are not traveling through the cycle.
Changing stock levels—
sequestering or releasing water or carbon—
affects the climate as ice or carbon dioxide interacts with the planet's weather system.**

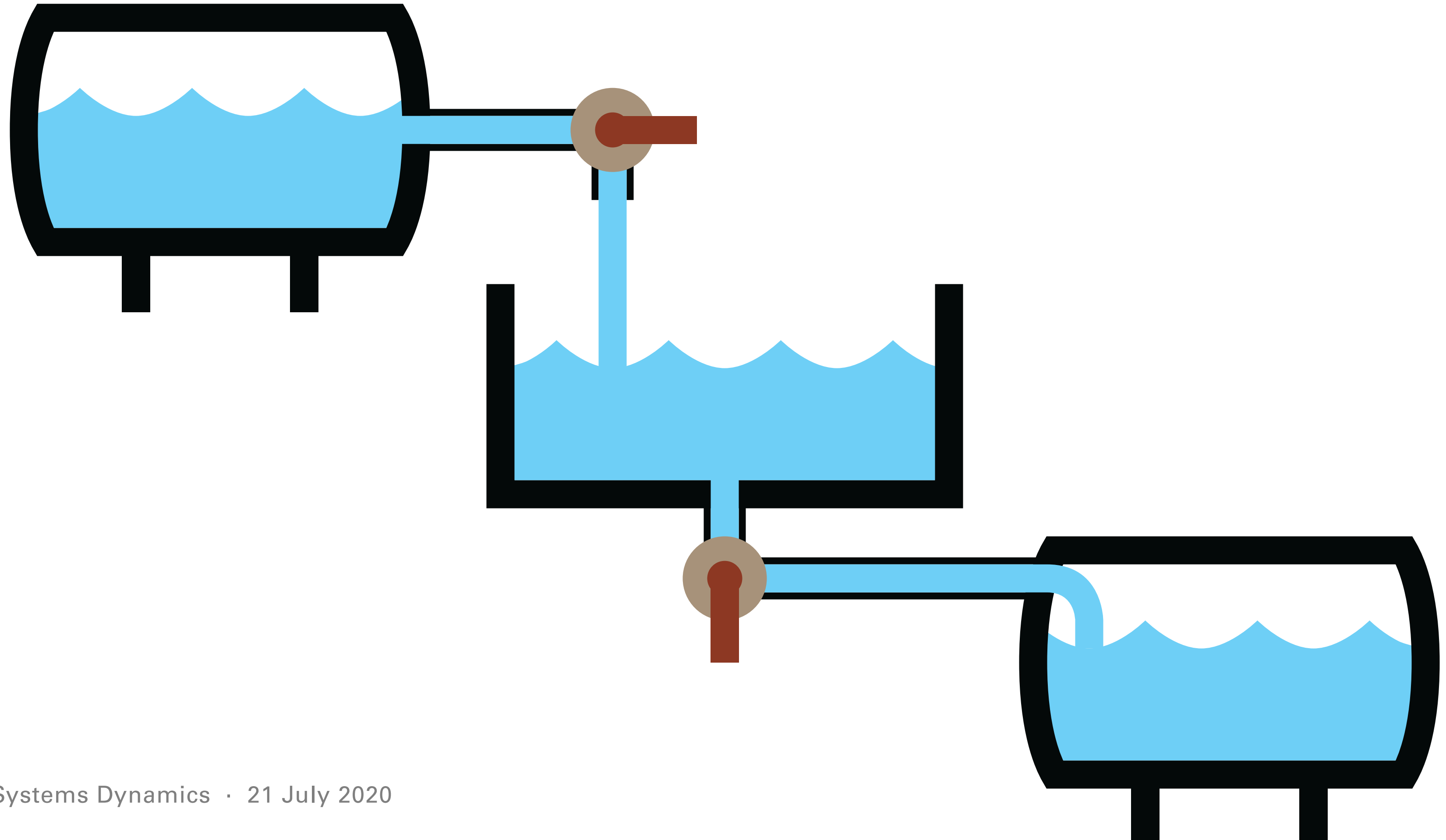


The phrase cradle-to-cradle suggests we build products so that they can be disassembled and recycled.

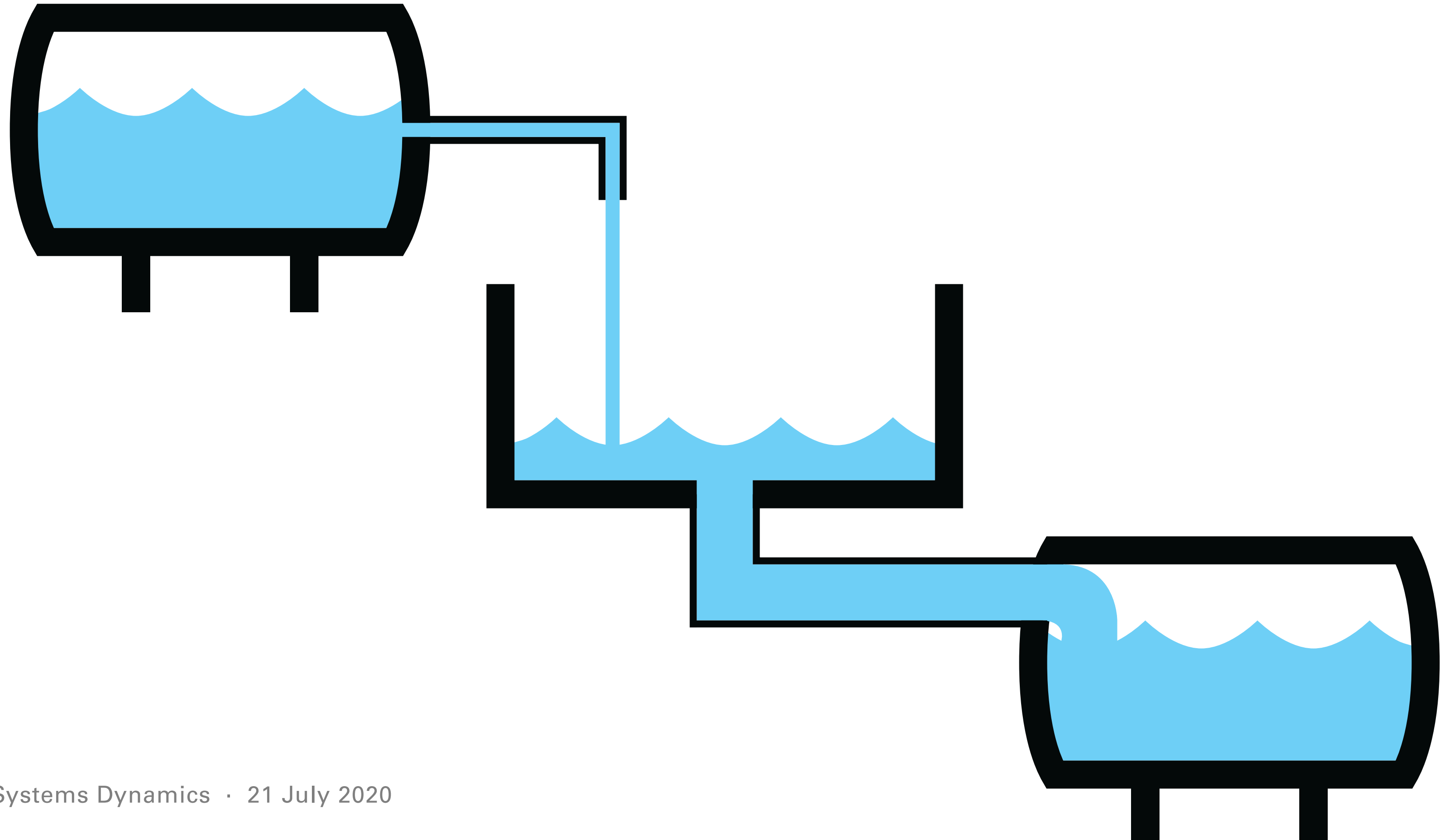
Biosphere + technosphere



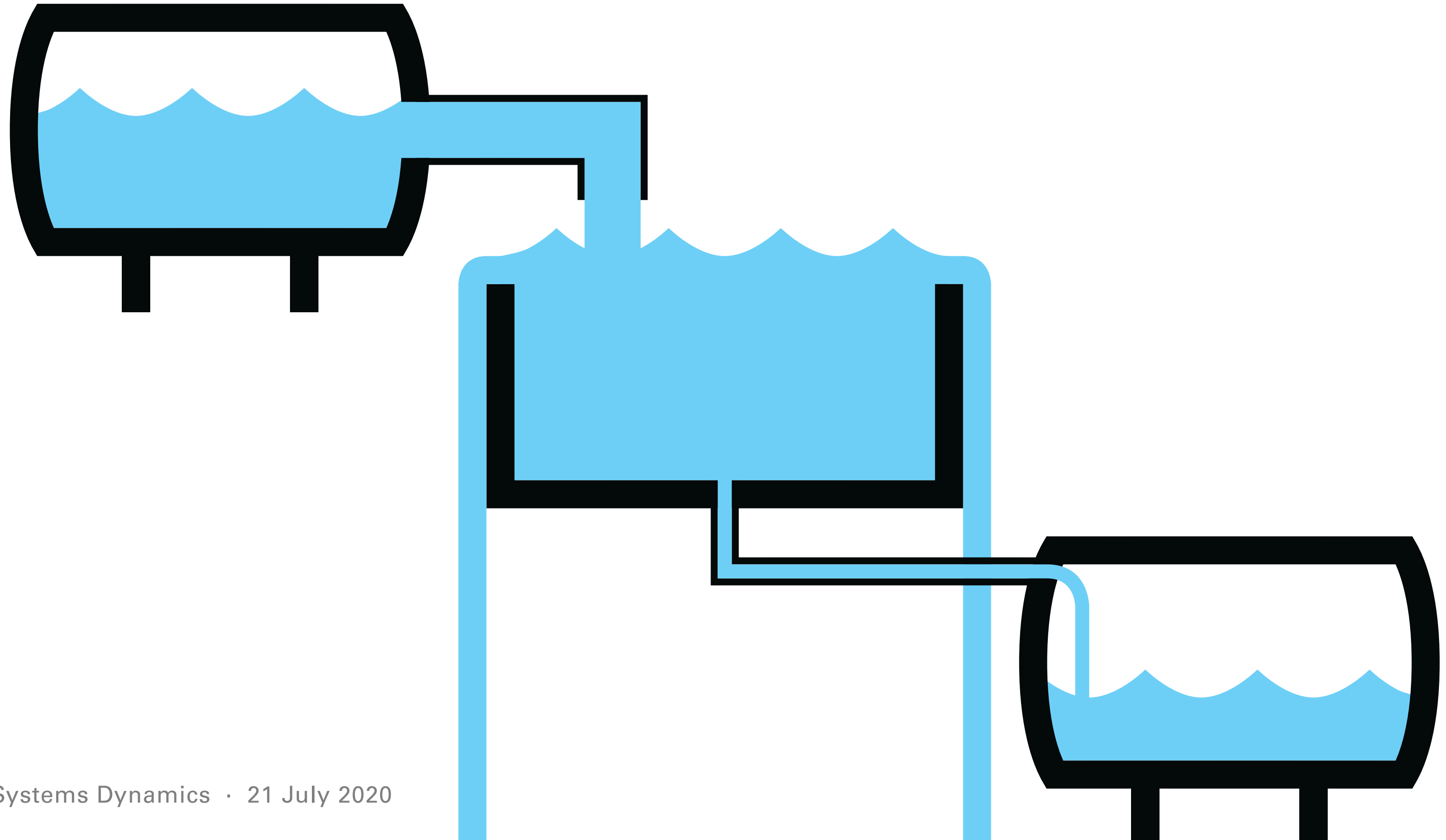
For a given stock,
the rate of inflow and the rate of outflow may change;
we can open or close a valve.



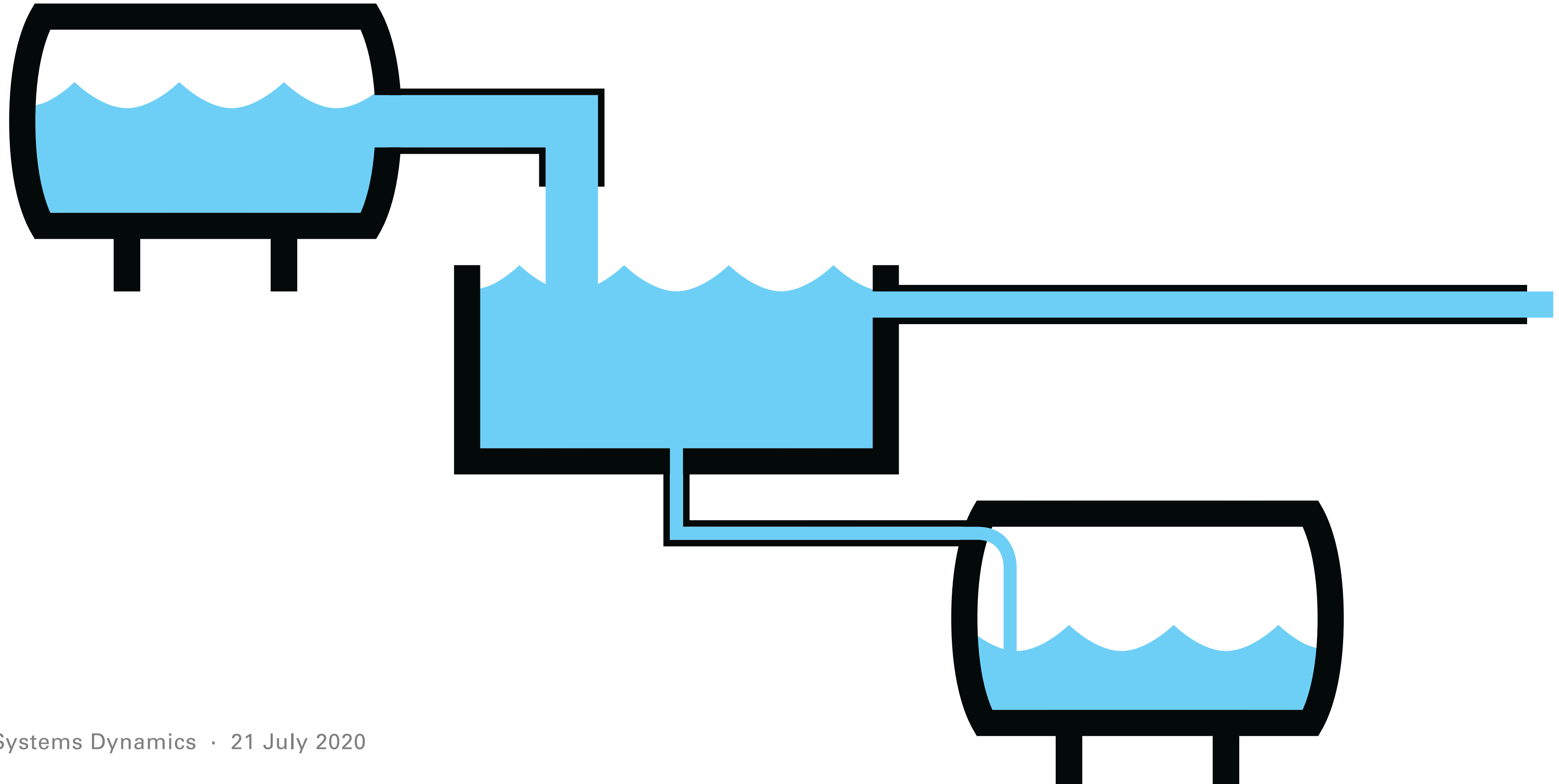
If ‘the rate of inflow’ < ‘the rate of outflow’, the tub will drain.



If ‘the rate of inflow’ > ‘the rate of outflow’, the tub will reach capacity and overflow.

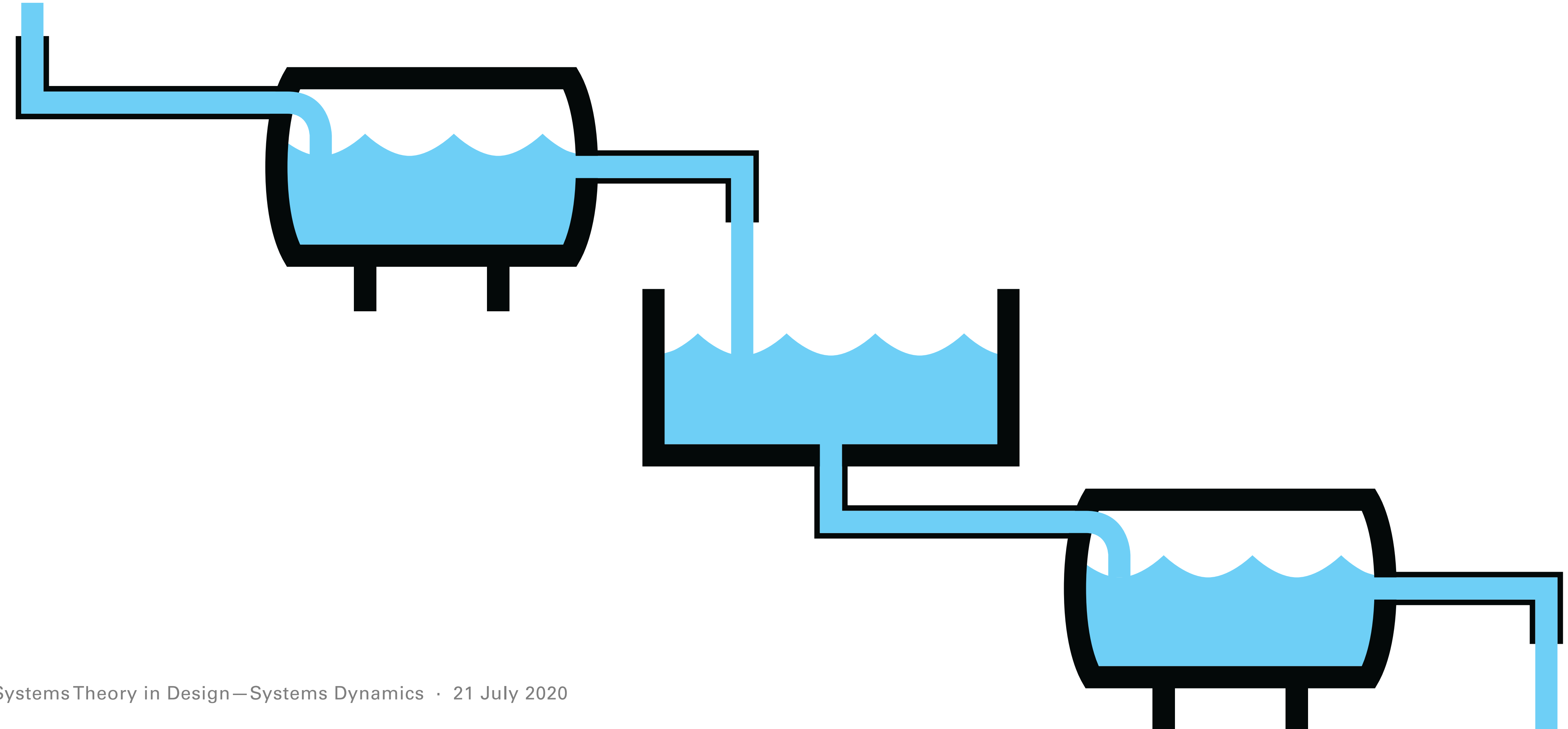


Most bathrooms tubs include an overflow drain, which automatically prevents spills.

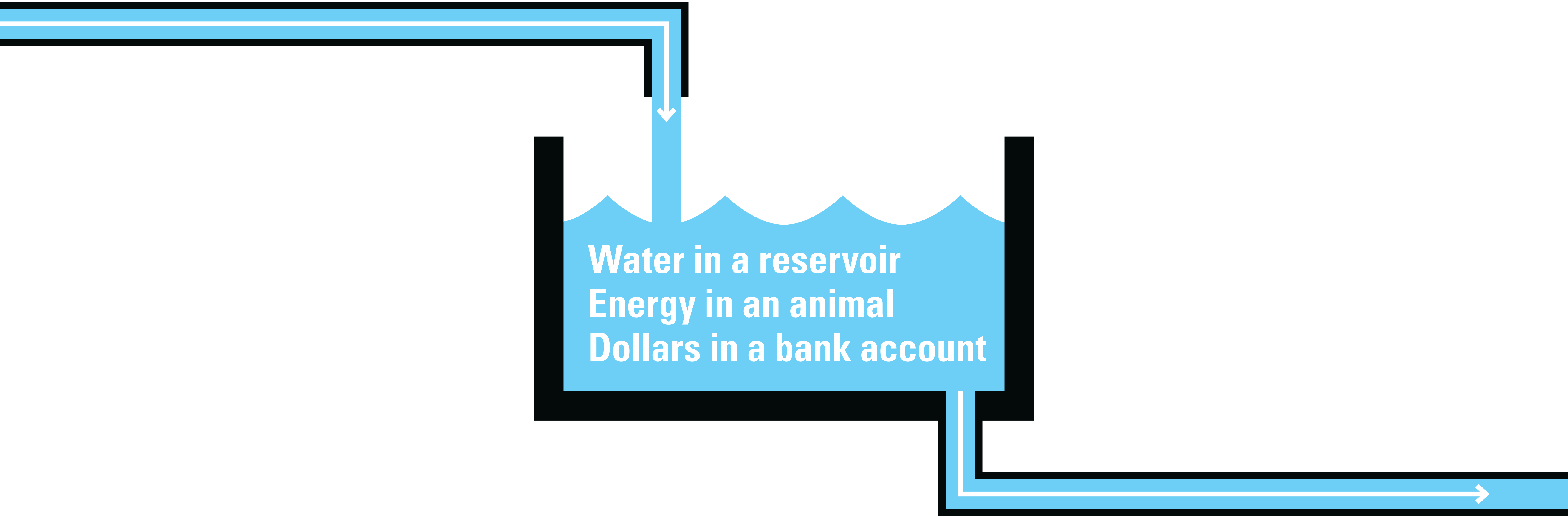


Man-made dams often include spillways to protect the dam from any overflow that might weaken it.

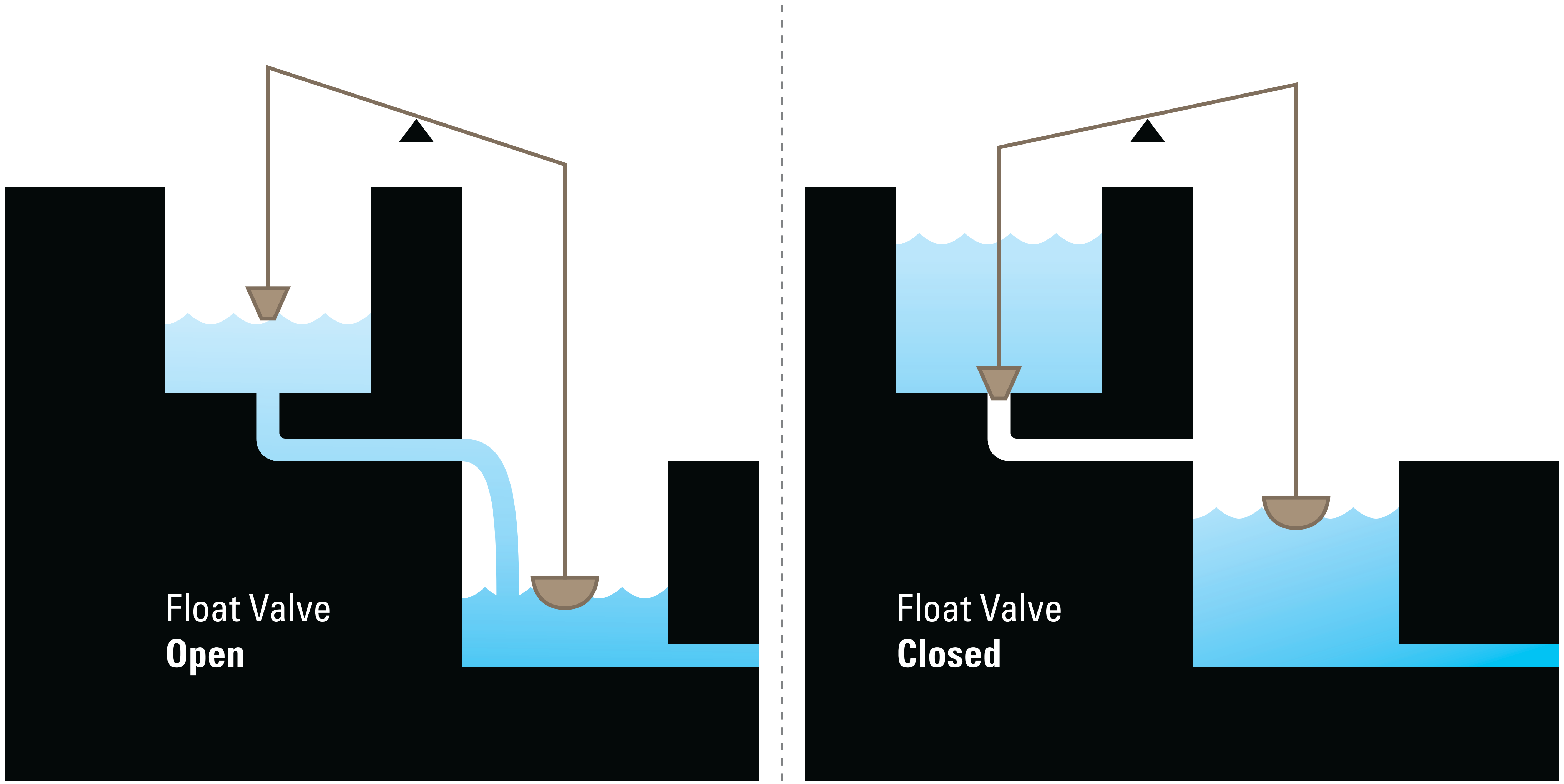
When ‘the rate of inflow’ = ‘the rate of outflow’, the system is in dynamic equilibrium; that is, the water level in the tub remains constant even though water is flowing in and out.



Dynamic equilibrium is a state of balance—
a resource that stays at the same level
even as it flows through a system.



For almost 2,000 years, people have used float valves to automatically reduce or shut off in-flow.

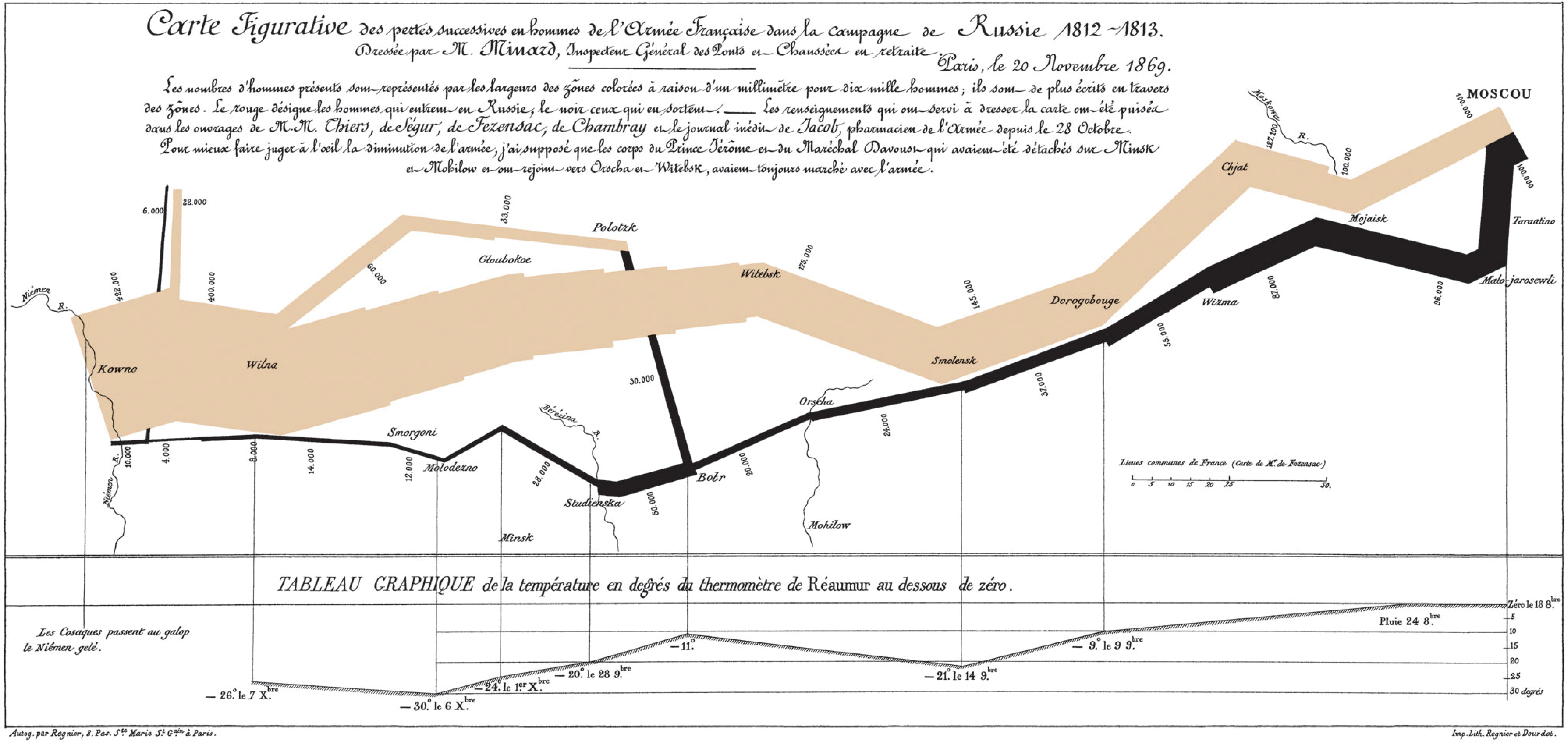


Float valves are part of modern toilets, automatically controlling the water flowing into the storage tank.

Stocks-and-flows diagrams can be used to model many kinds of systems:

- Populations
- Production and sales of goods
- Shipping
- Finances

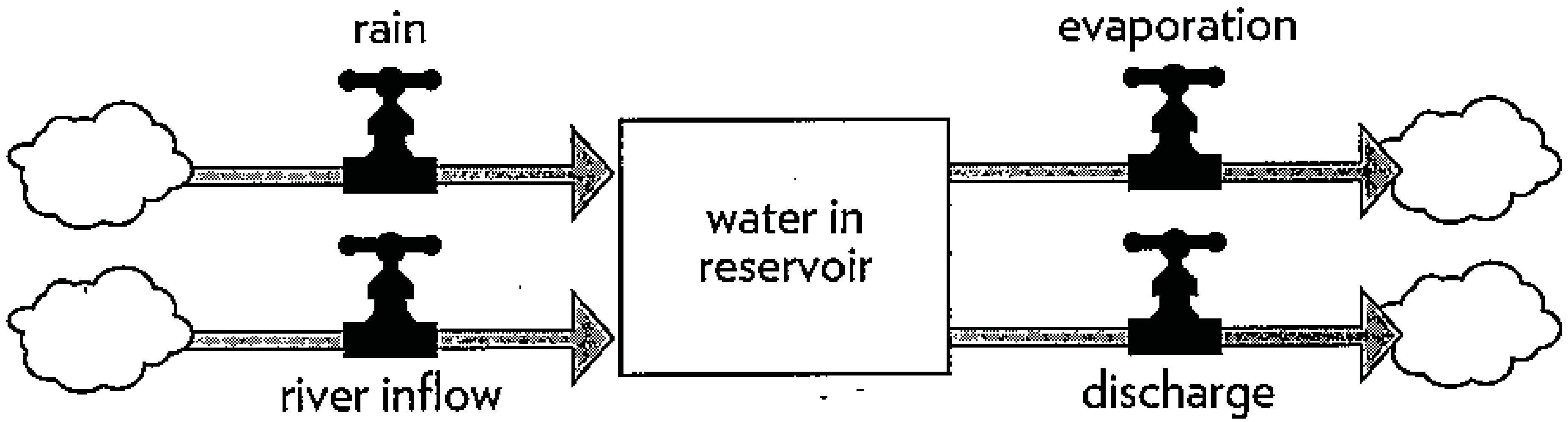
Minard's model of Napolean's march on Moscow.



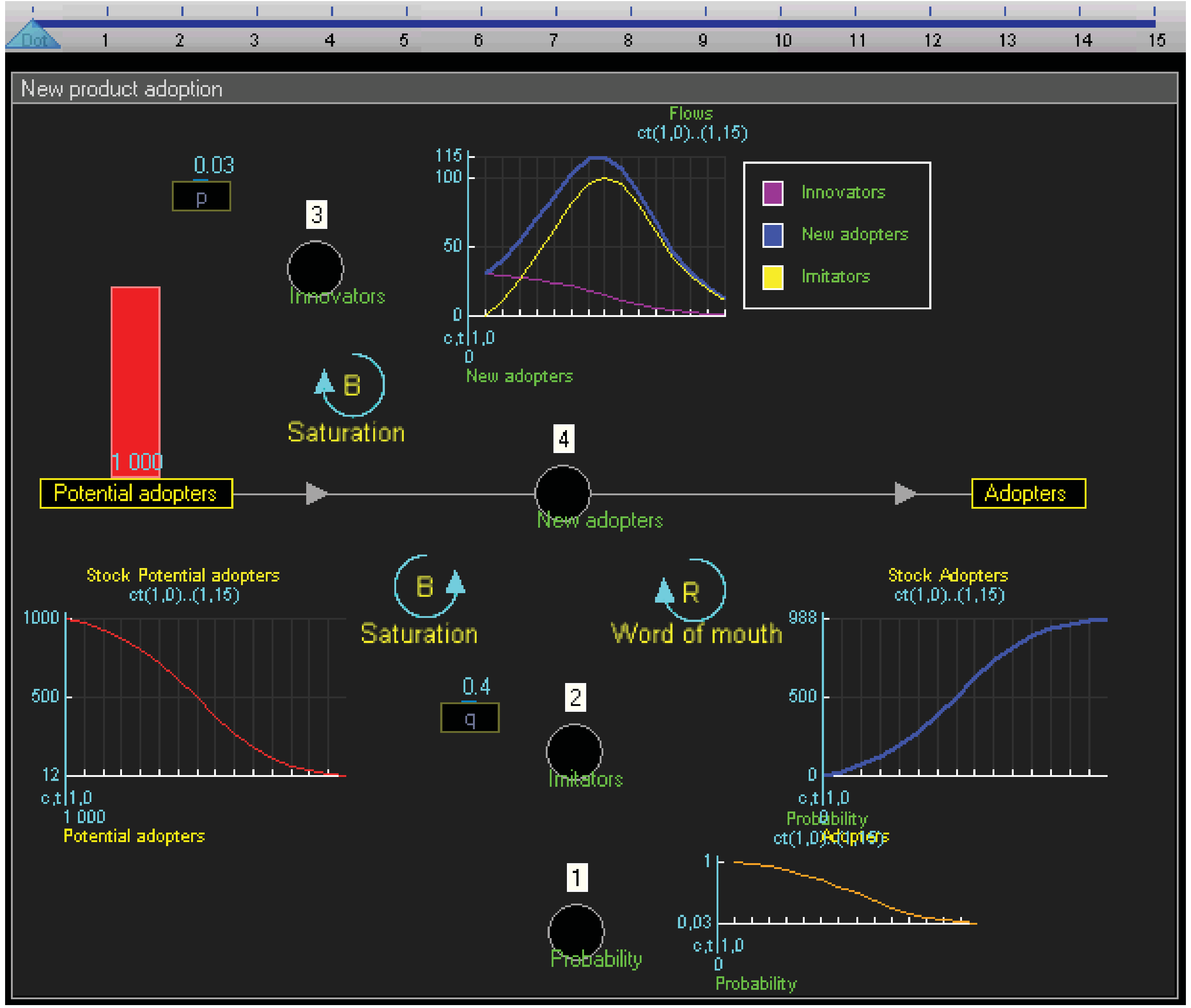
Flight density between international airports.

Stocks and flows can be represented in a number of visual forms.

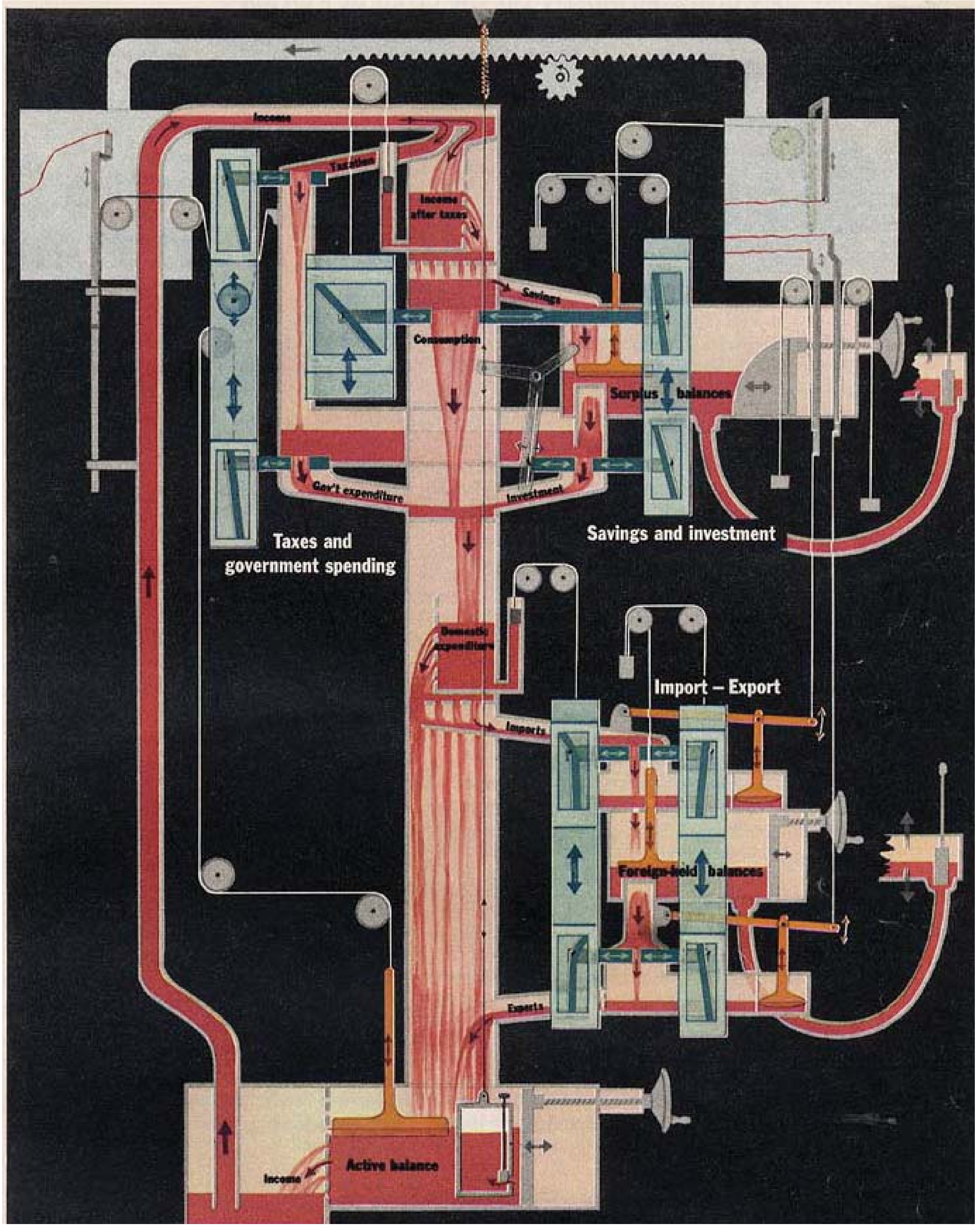
From: Donella Meadows, *Thinking in Systems*



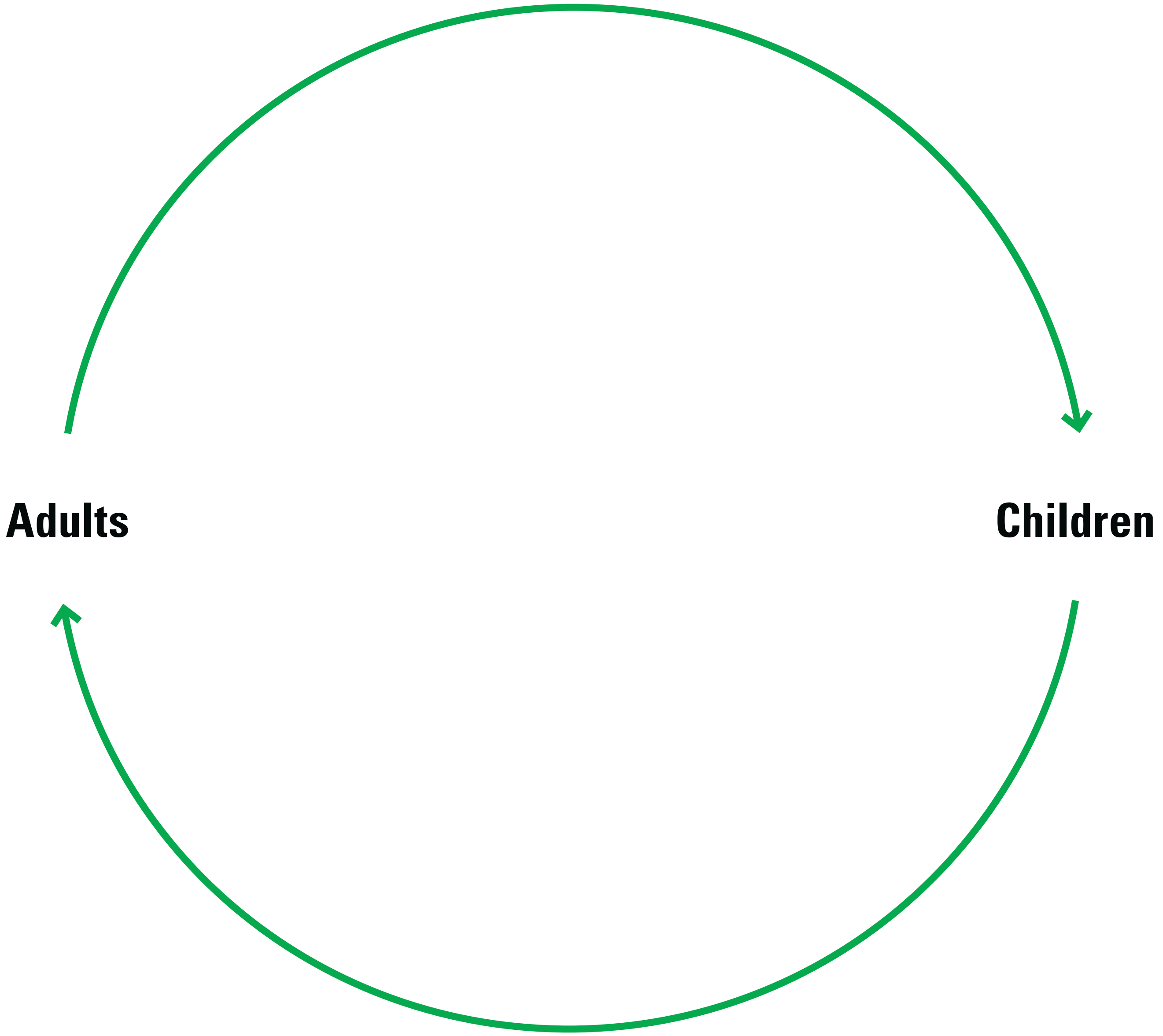
Stocks and flows can also be represented mathematically and in computer simulations.



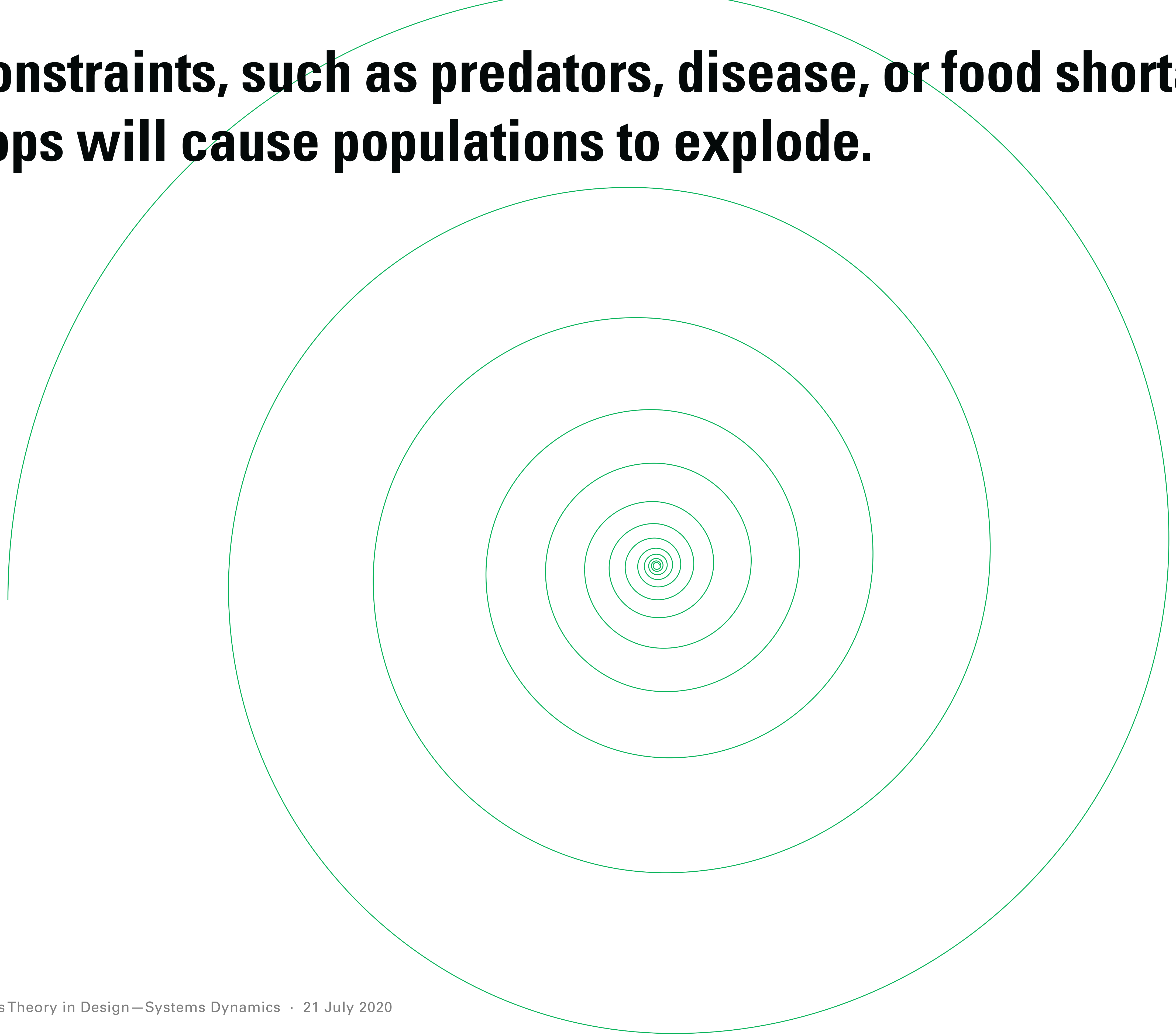
The MONIAC or Phillips Hydraulic Computer represents the UK economy with stocks and flows of water.



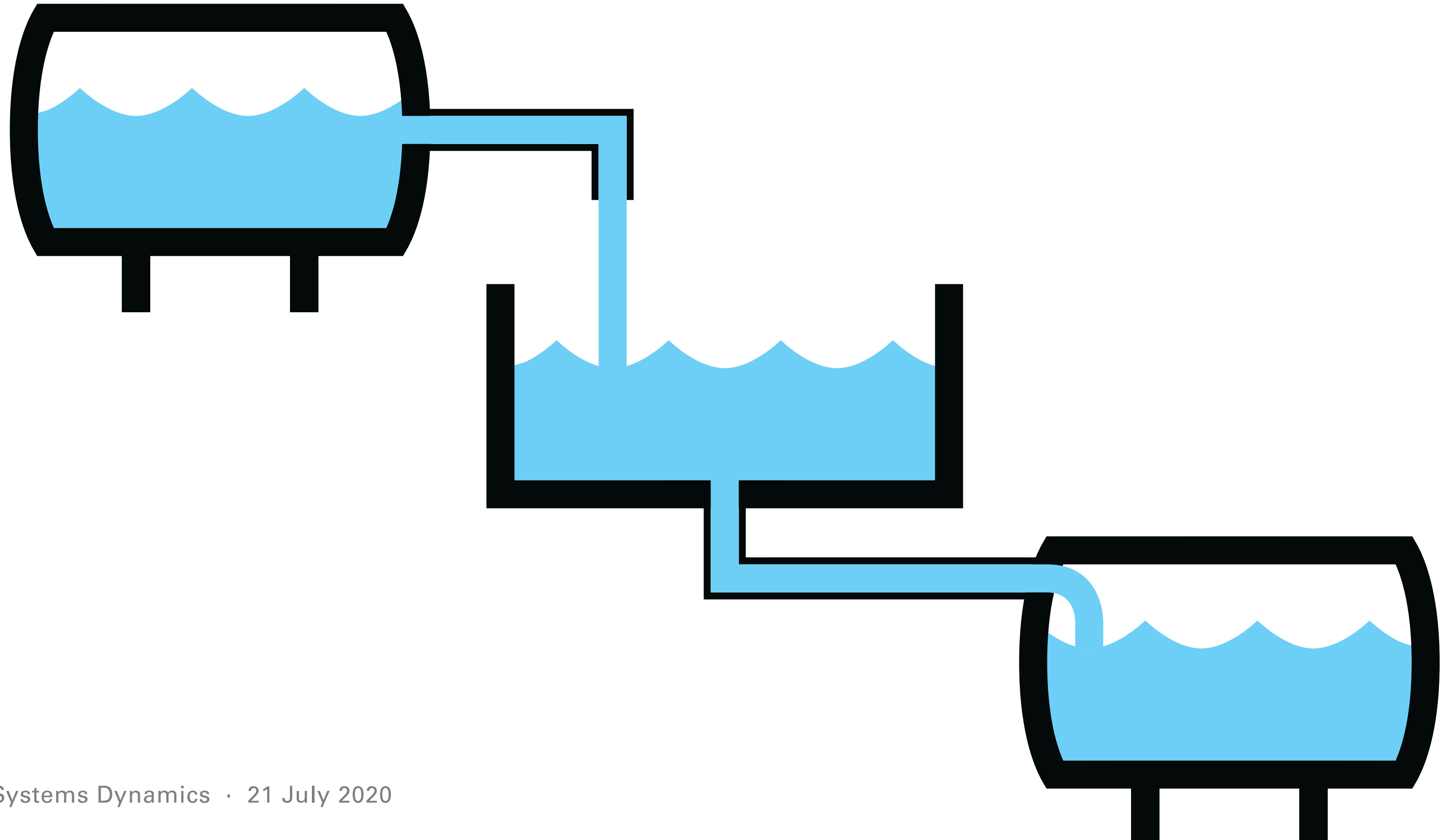
Living systems also form growth loops or virtuous cycles; adults beget children who may become adults.



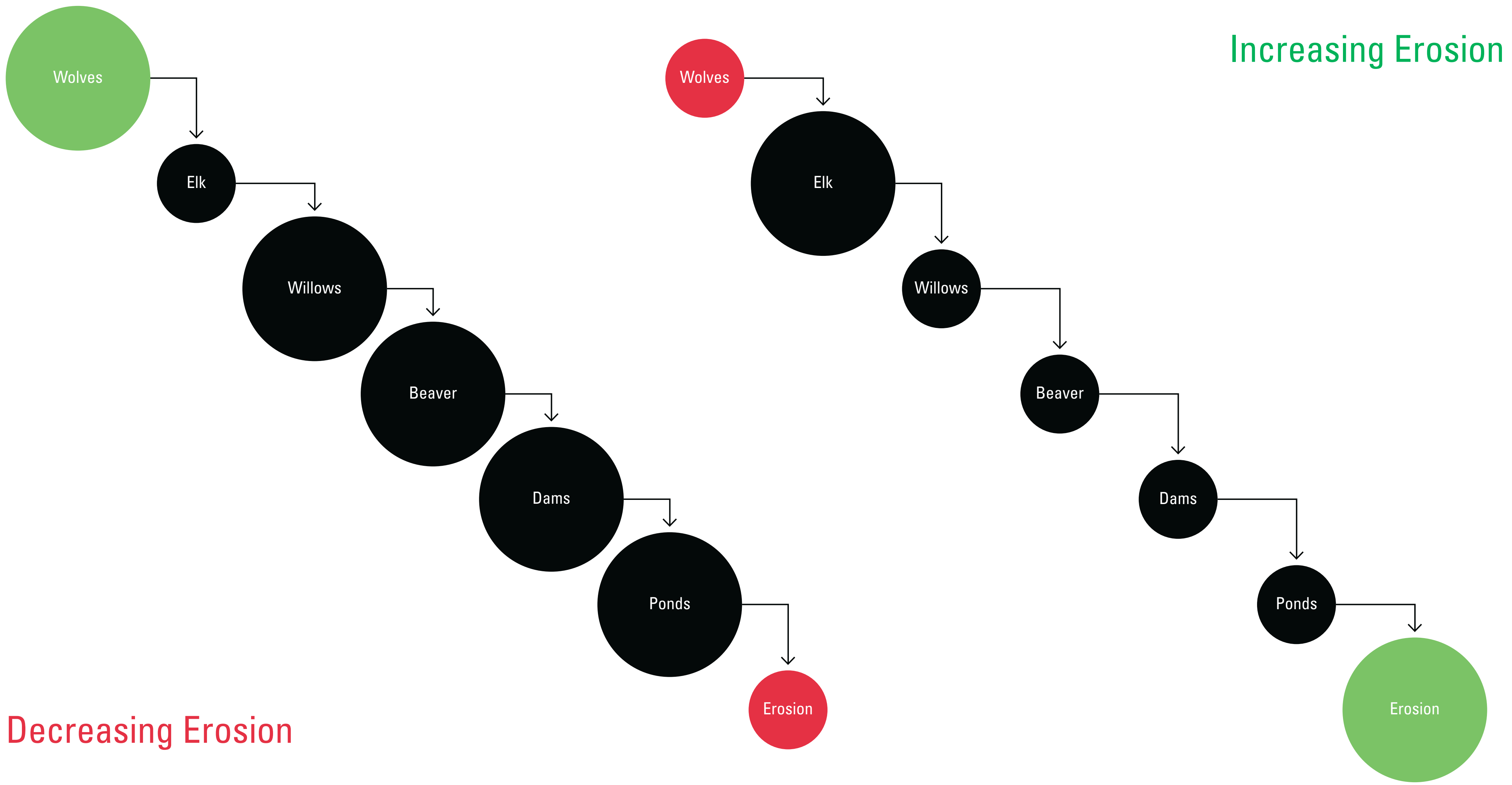
Without constraints, such as predators, disease, or food shortages, growth loops will cause populations to explode.



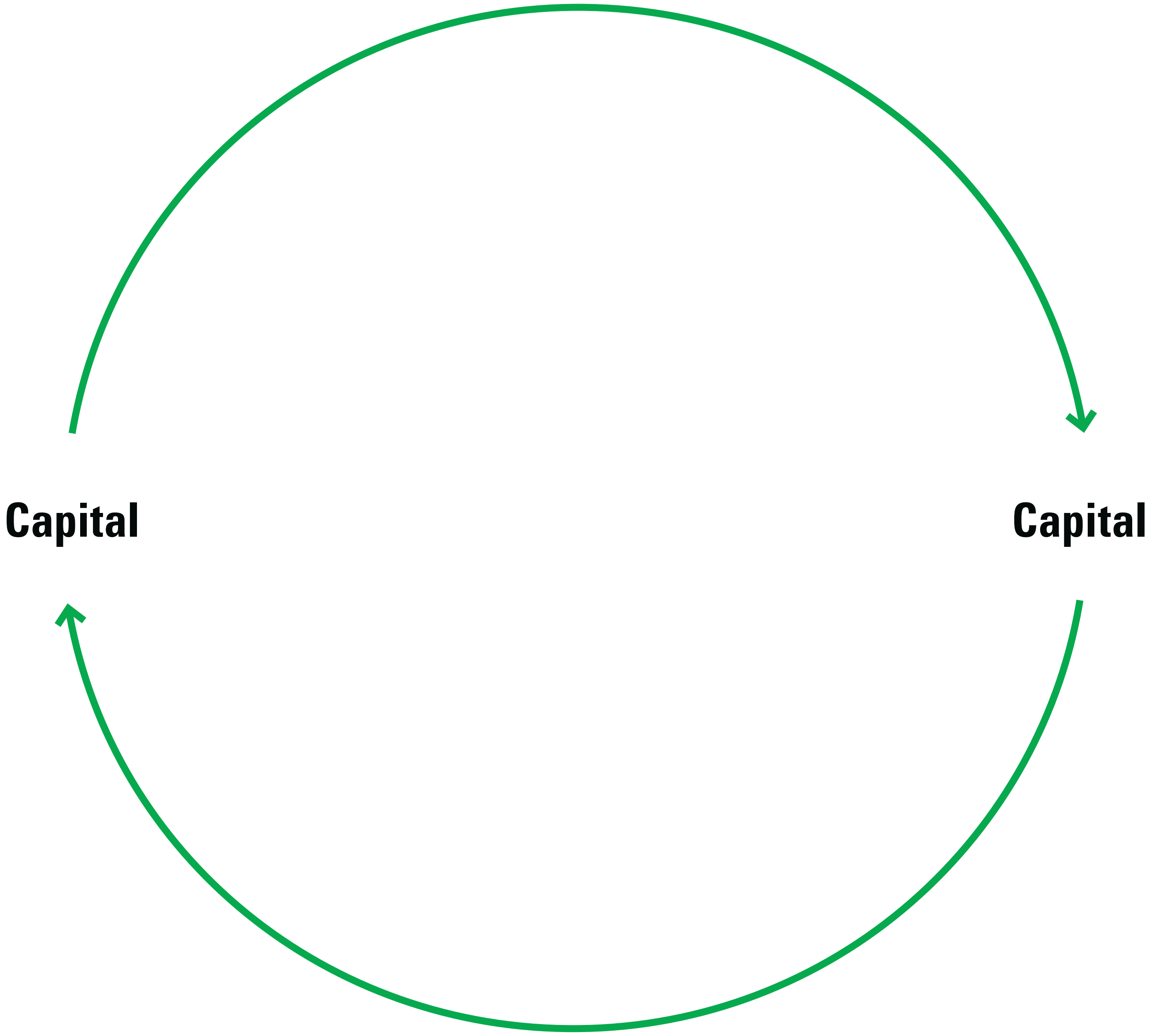
Mature ecosystems reach points of dynamic equilibrium; populations remain stable—
the number of births = the number of deaths.



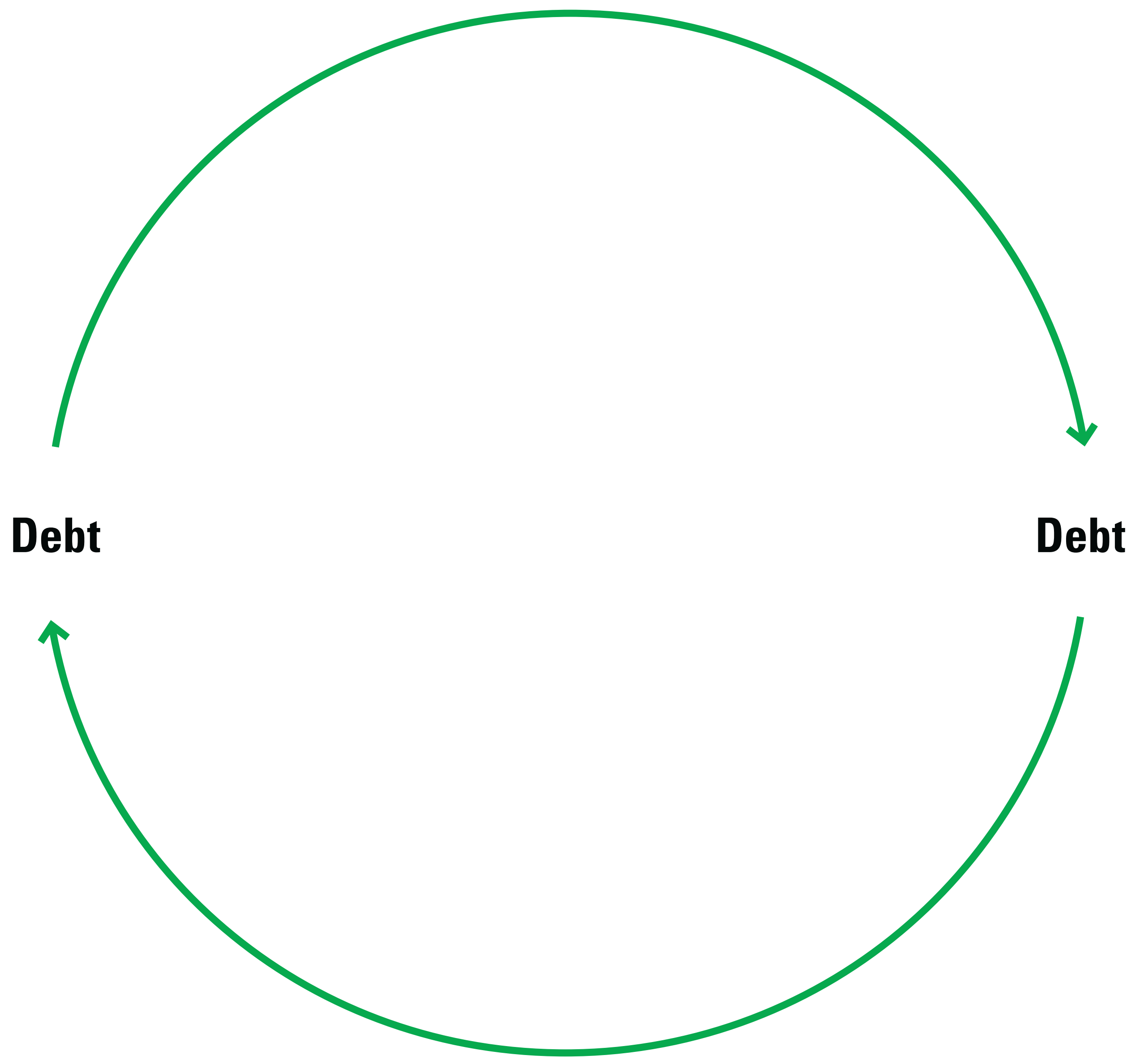
Disturbances from outside the system may throw it out of balance and result in a new, much different point of equilibrium, often with drastic consequences for existing population stocks.



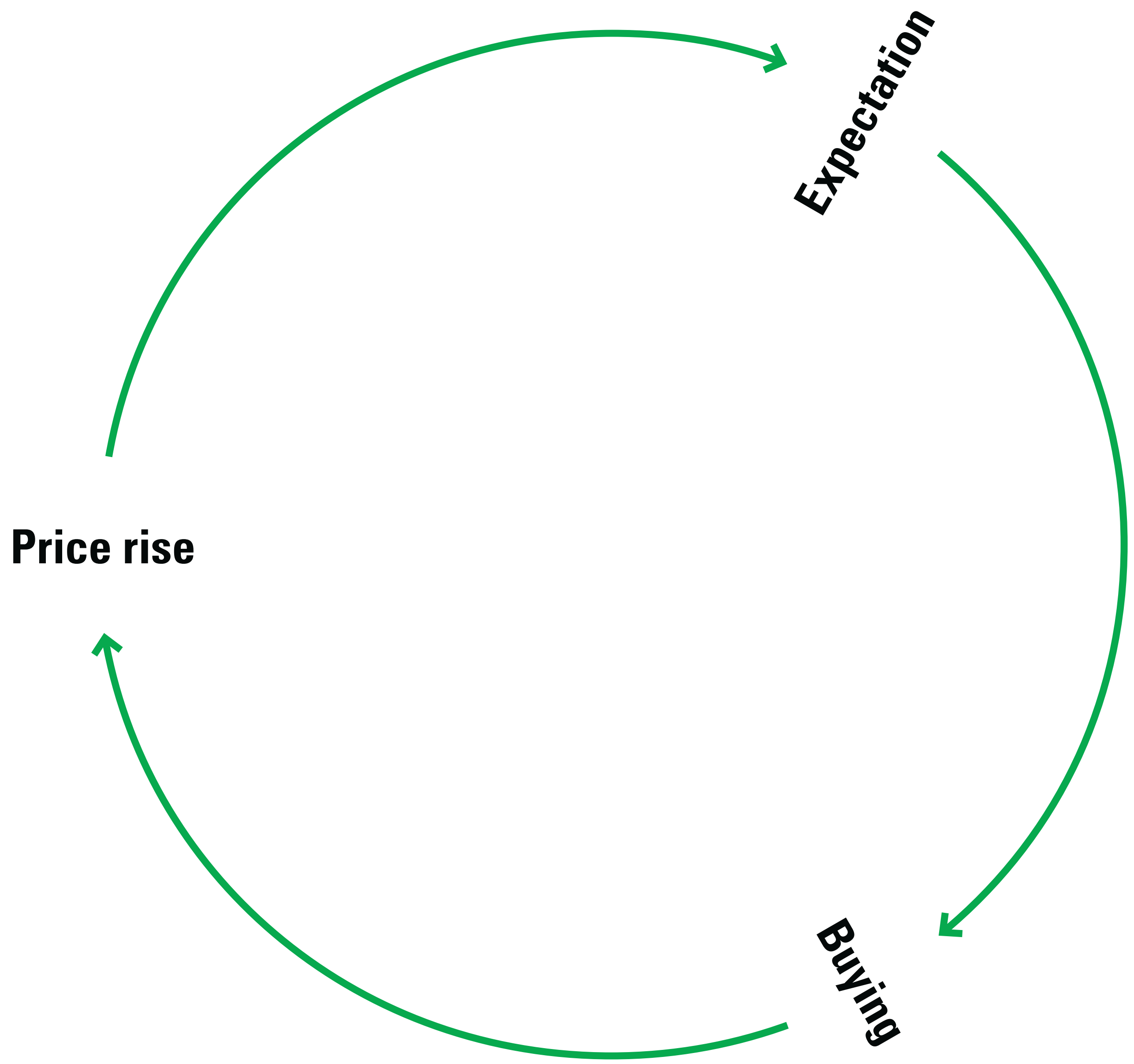
Interest paid on stocks of money also form a growth loop; capital leads to more capital.



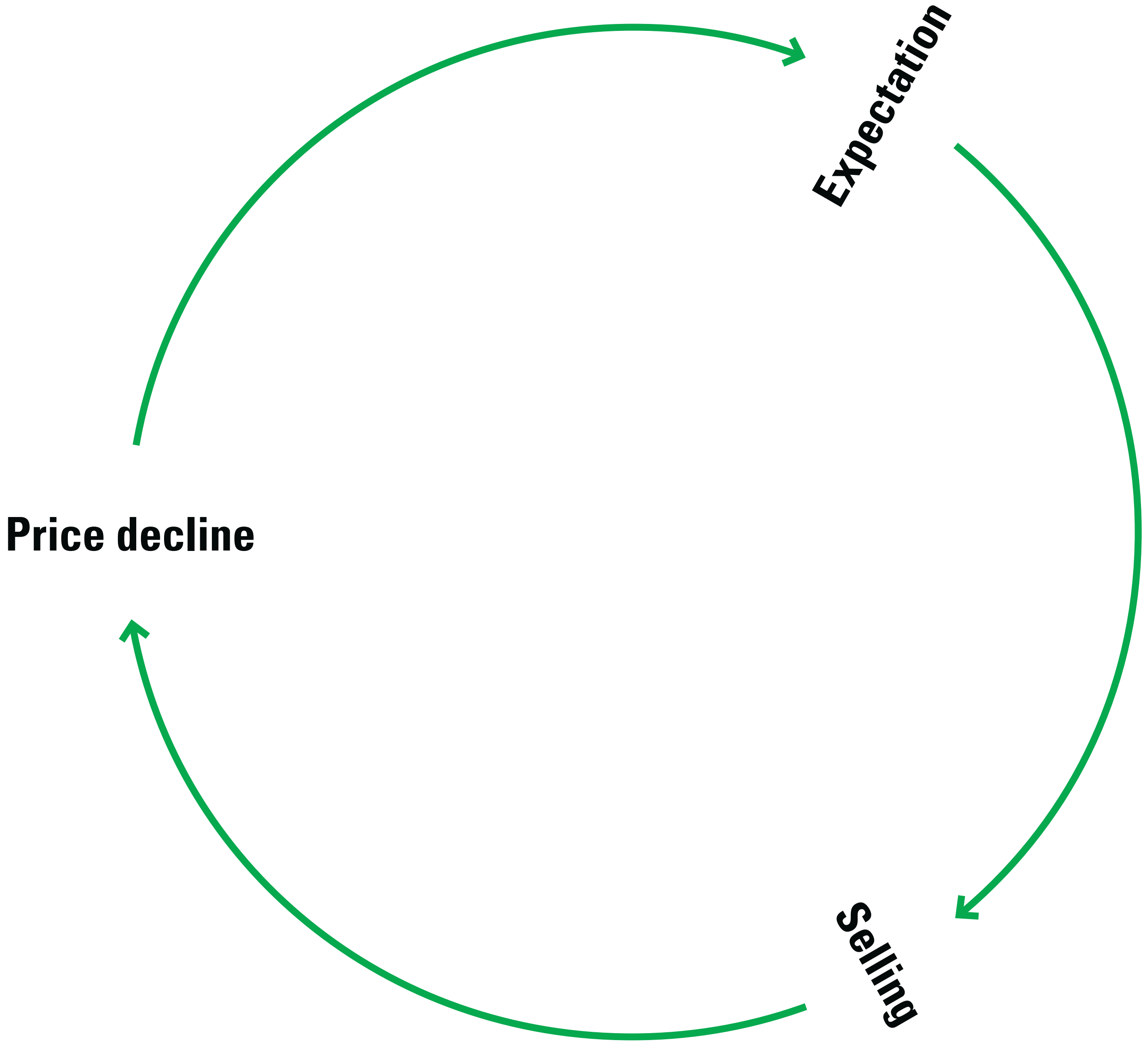
Likewise debt can lead to more debt, forming a collapse loop or vicious cycle.



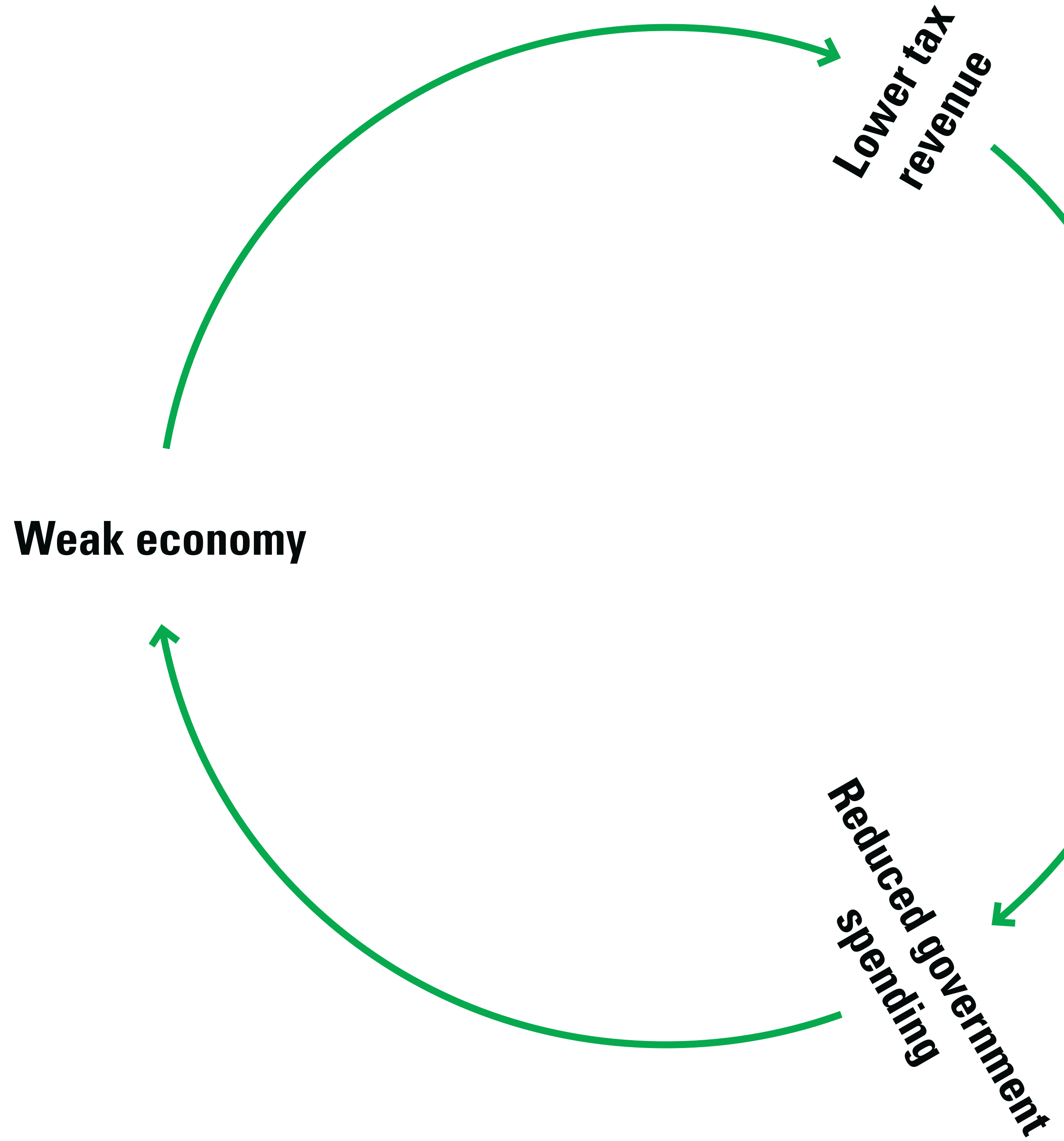
Speculative bubble inflate in a similar way; a price rise leads to expectations of further rises, which lead to buying, which leads to price rises.



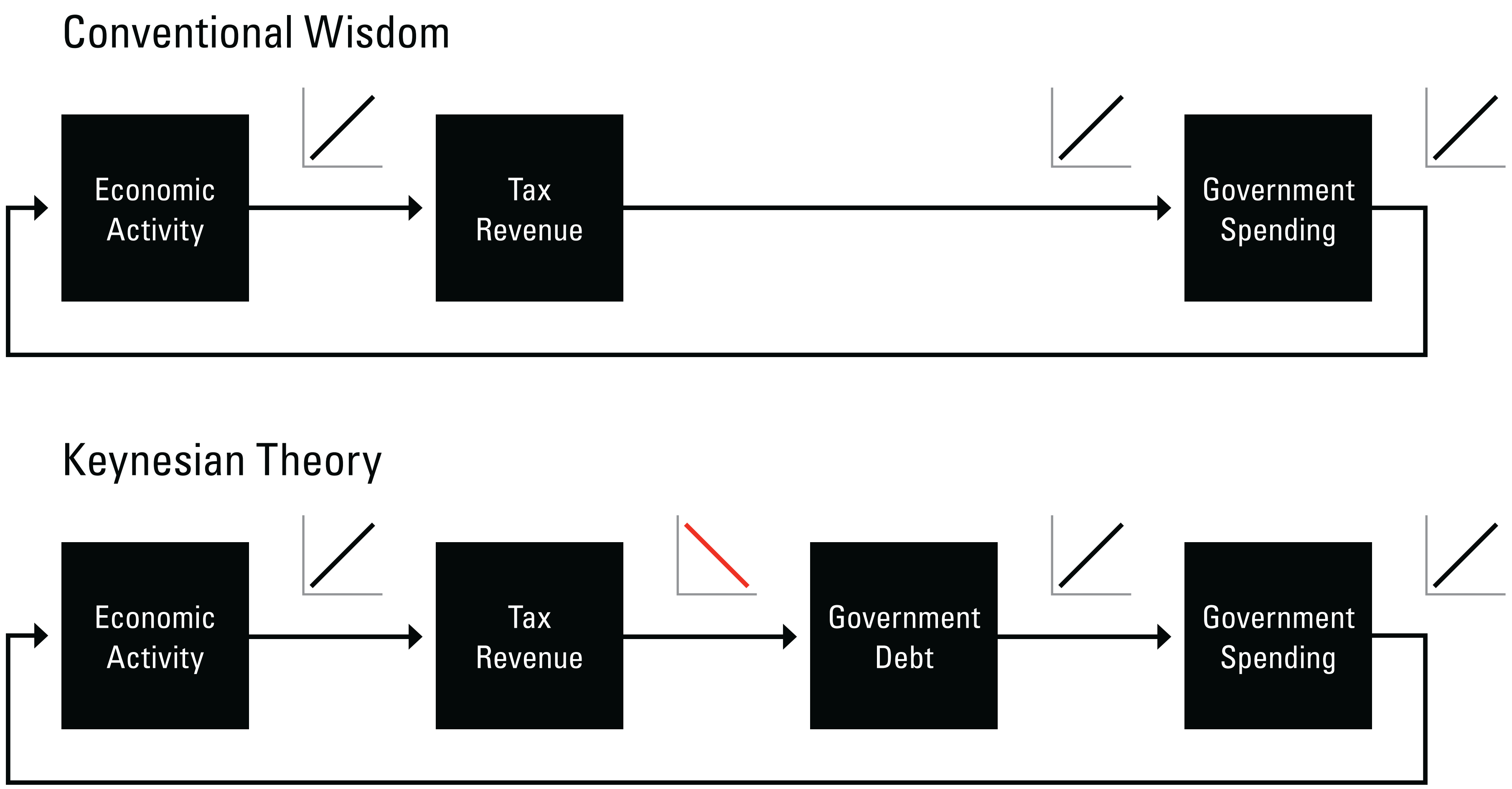
Bubbles crash
as expectations of price declines lead to selling, which leads to price declines, reinforcing expectations.



A recession reduces tax revenue, which may reduce government spending, which further weakens the economy, creating a collapse loop, e.g., the Great Depression.

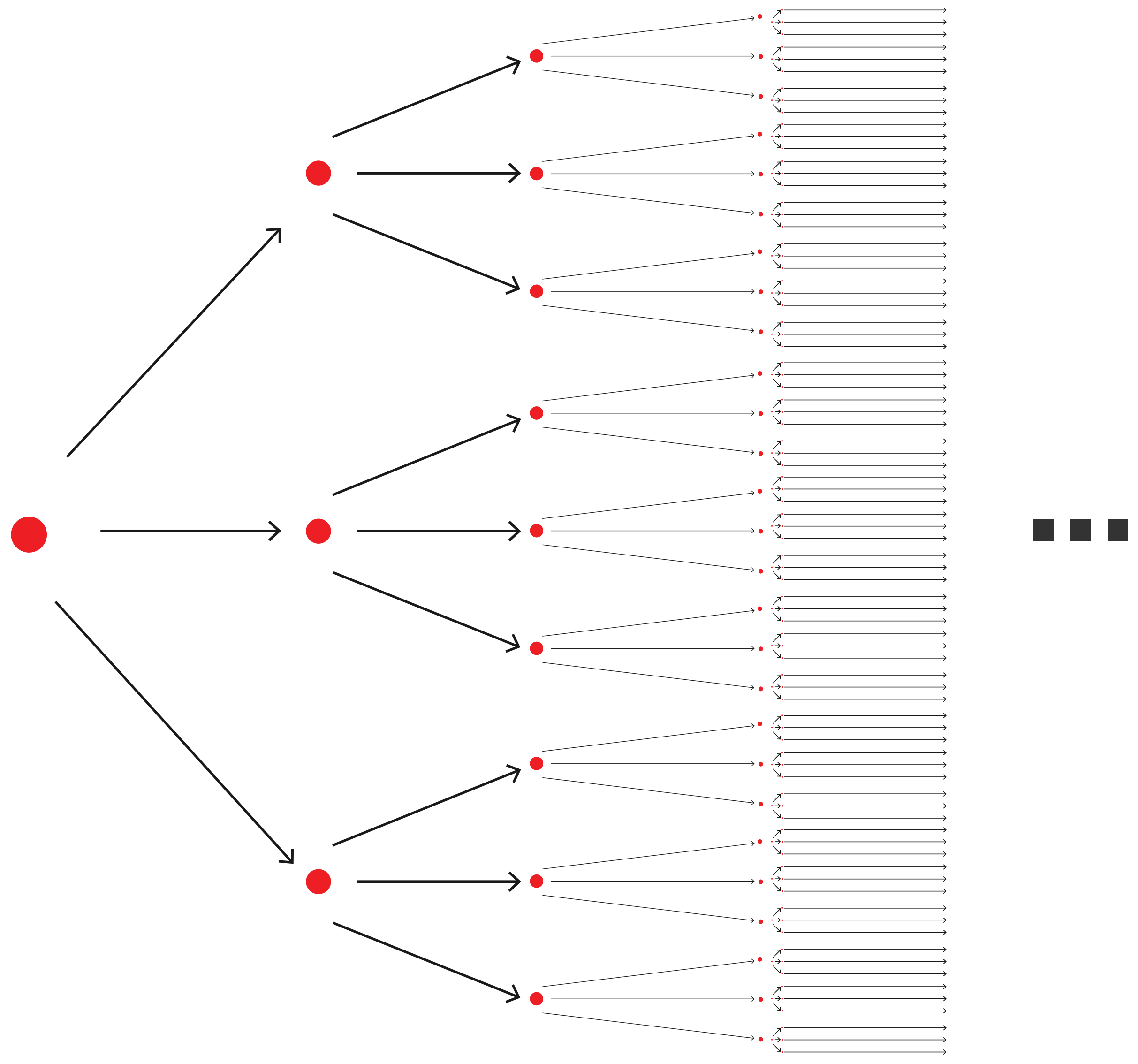


Keynes showed that increasing government spending during a recession (by taking on debt) can improve the economy, which avoids a collapse and puts the system back into balance.
As the economy improves, tax revenues increase, and government debt can be paid down.



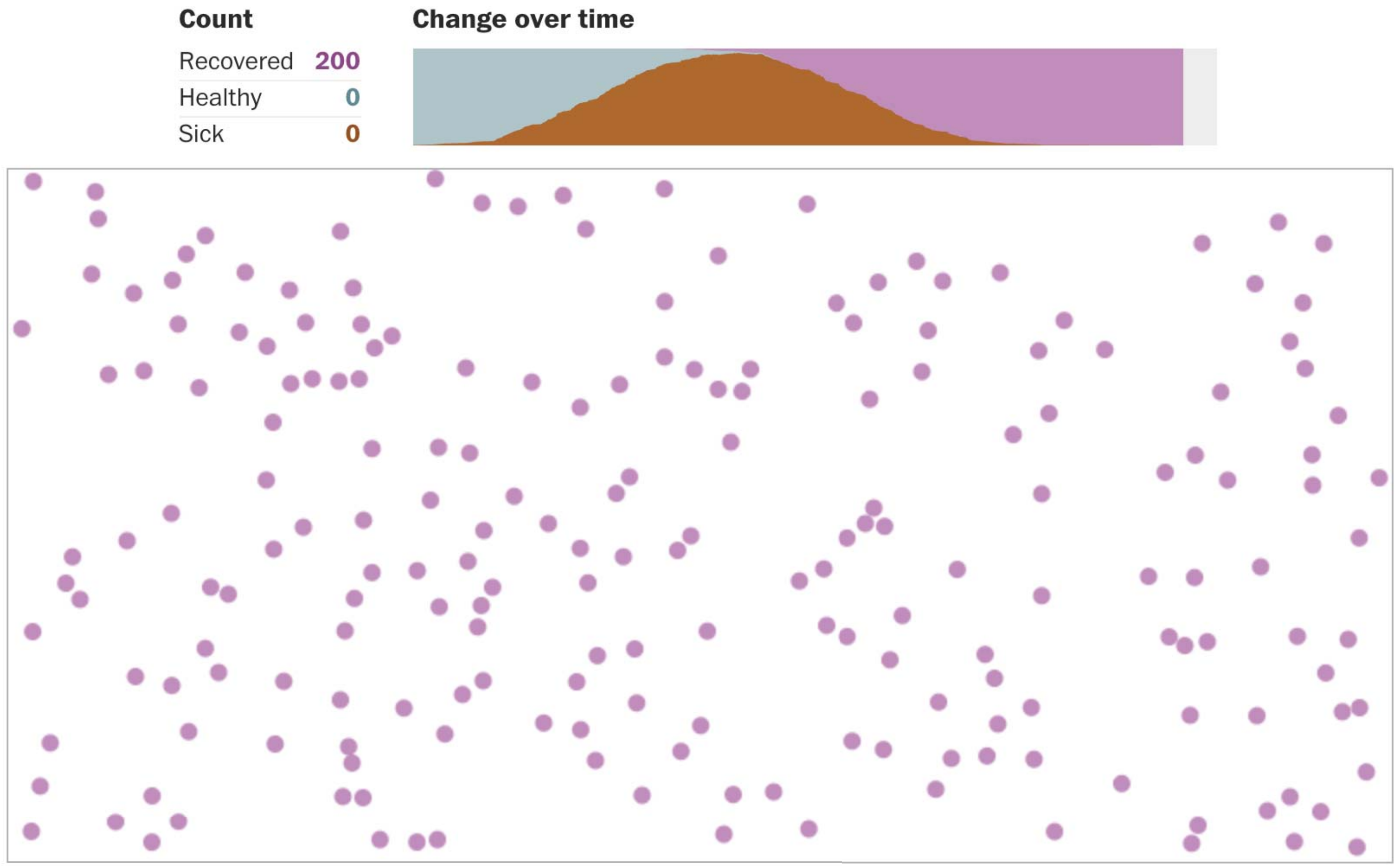
How might we model COVID-19?

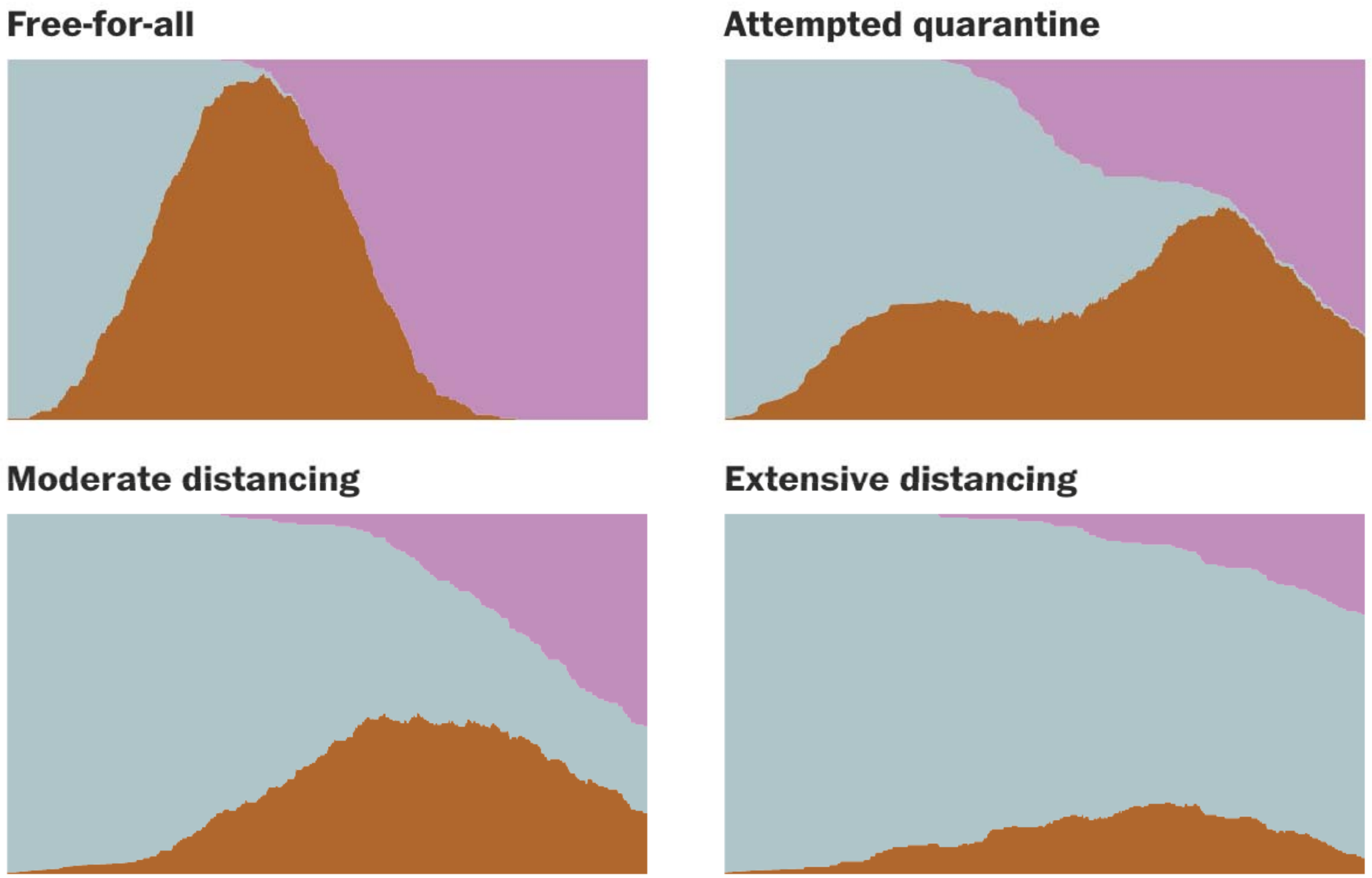
As a chain reaction —
One person infects 2 or 3 people, and they each infect 2 or 3 people.



$3^0=1$ $3^1=3$ $3^2=9$ $3^3=27$ 3^n

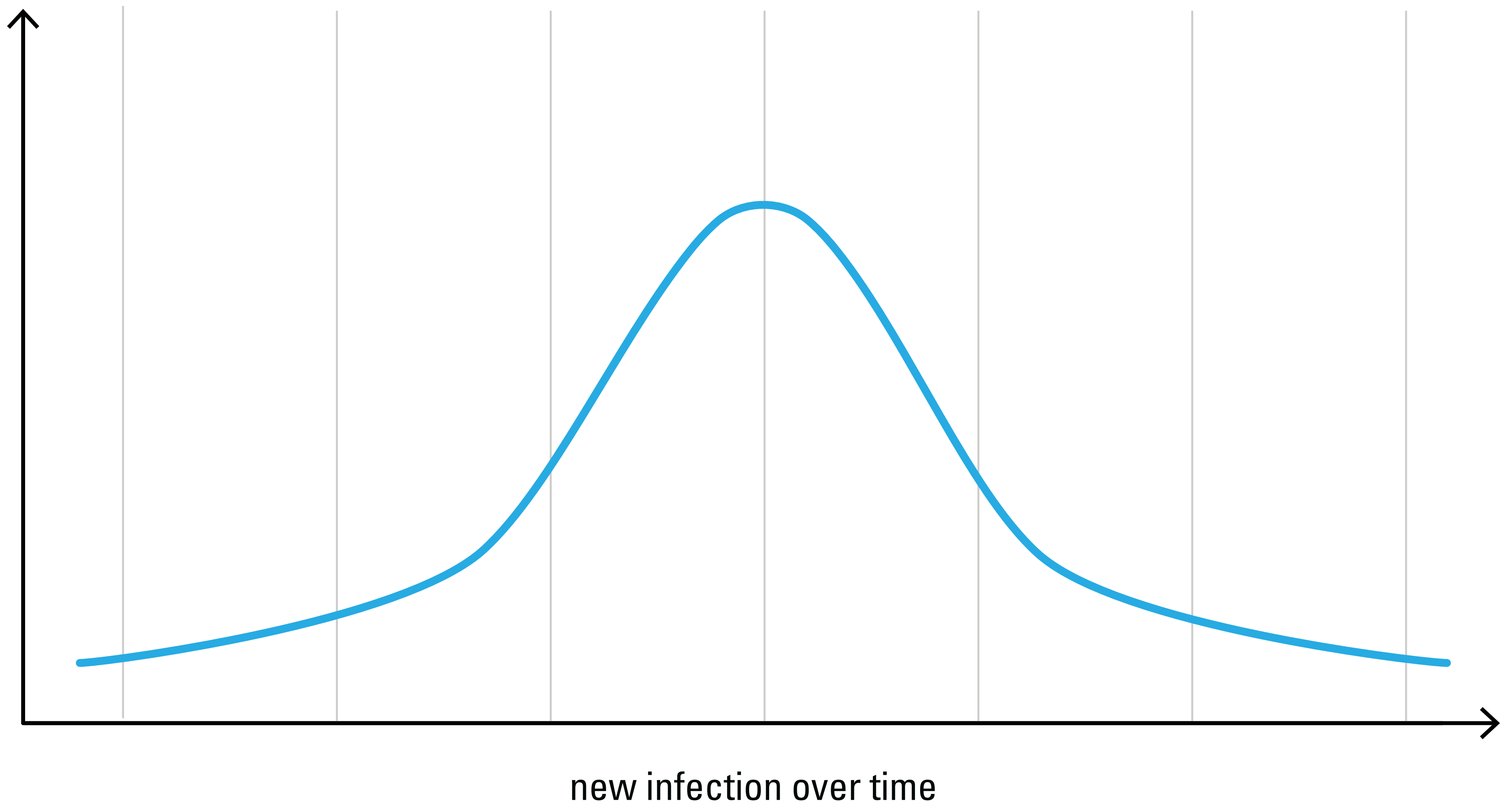
Why outbreaks like coronavirus spread exponentially, and how to “flatten the curve”, The Washington Post, Harry Stevens



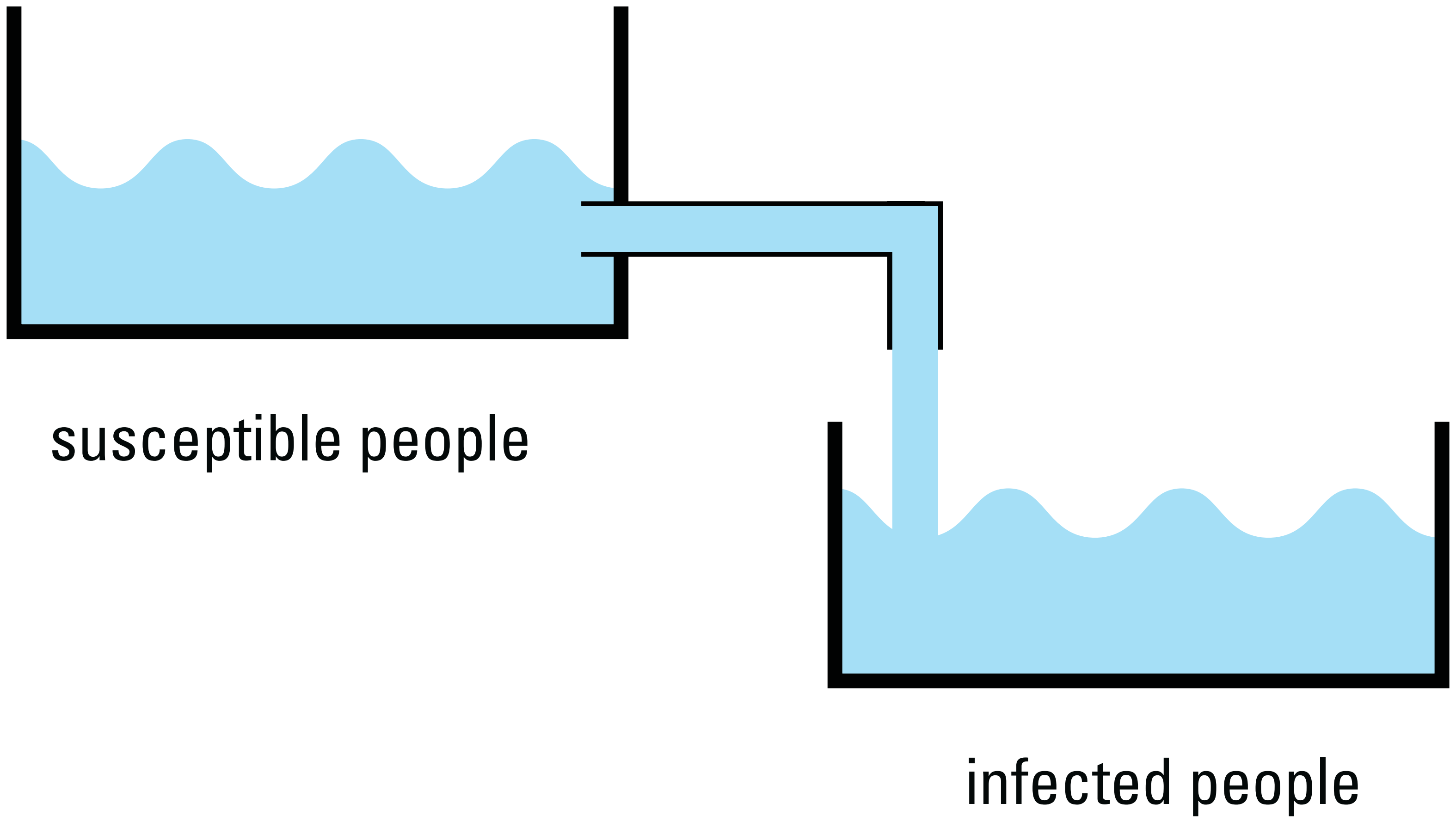


Credit: https://www.washingtonpost.com/graphics/2020/world/corona-simulator/

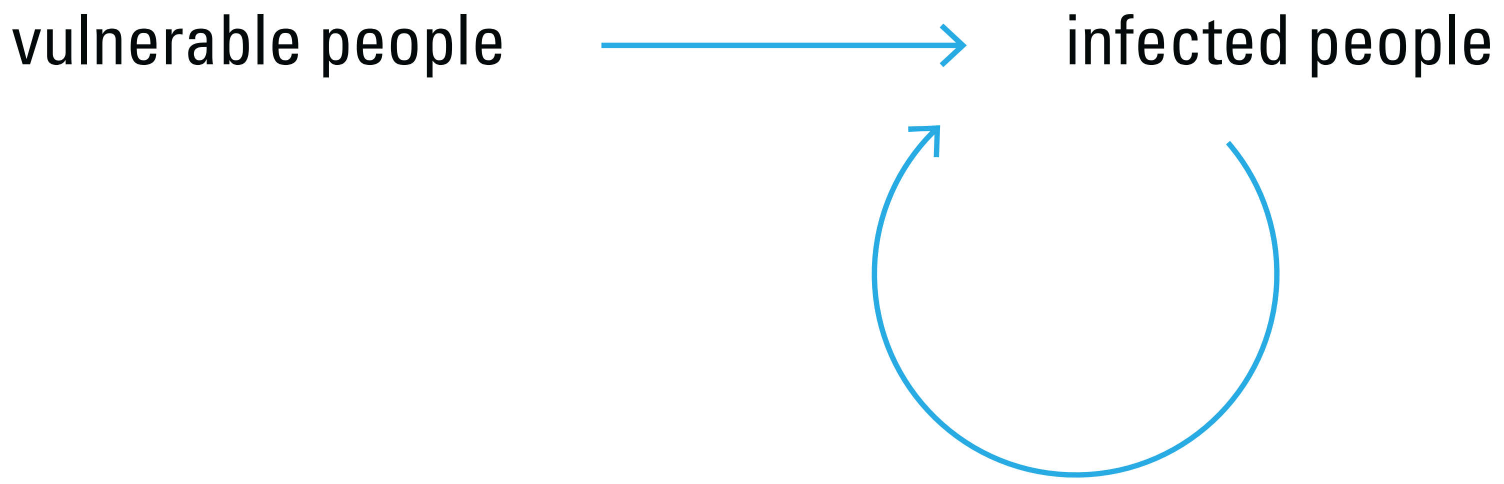
As a bell curve —
The infection rate grows exponentially, slows, and then declines as everyone is infected.



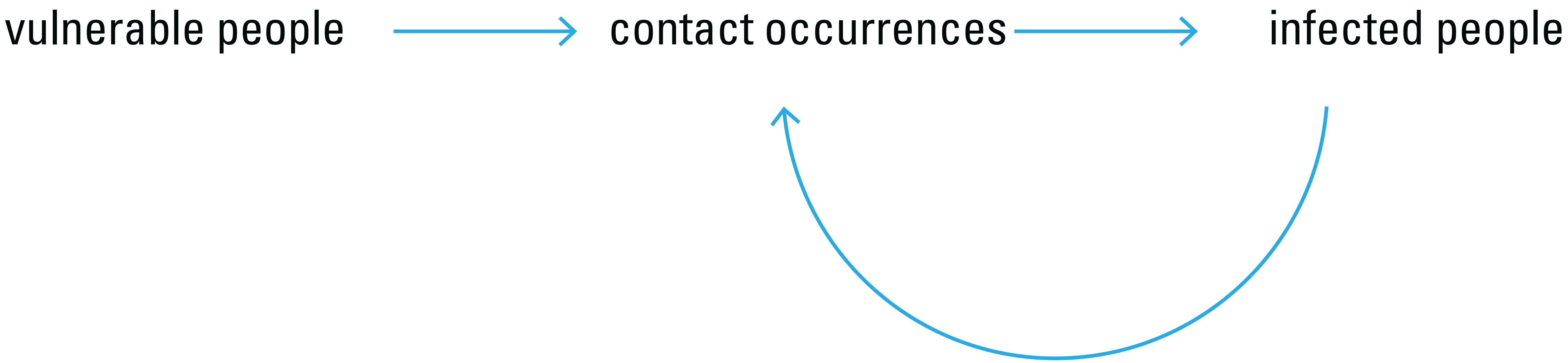
As simple stocks and flows —
Susceptible people become infected people.



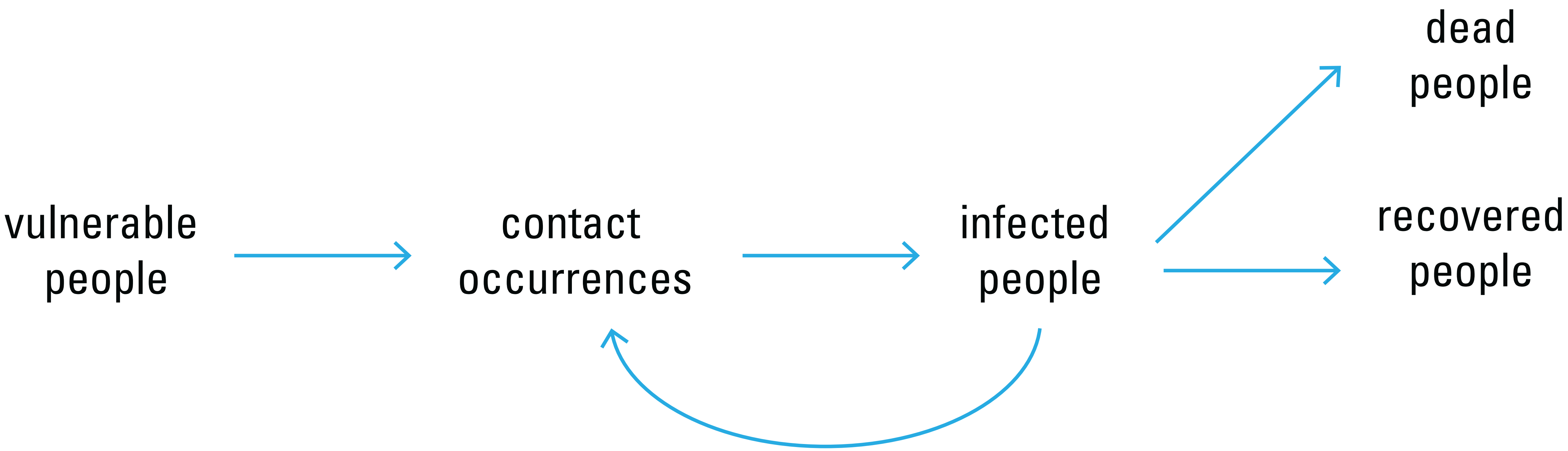
In the language of causal loop diagrams — Vulnerable people become infected people, and infected people lead to more infected people.



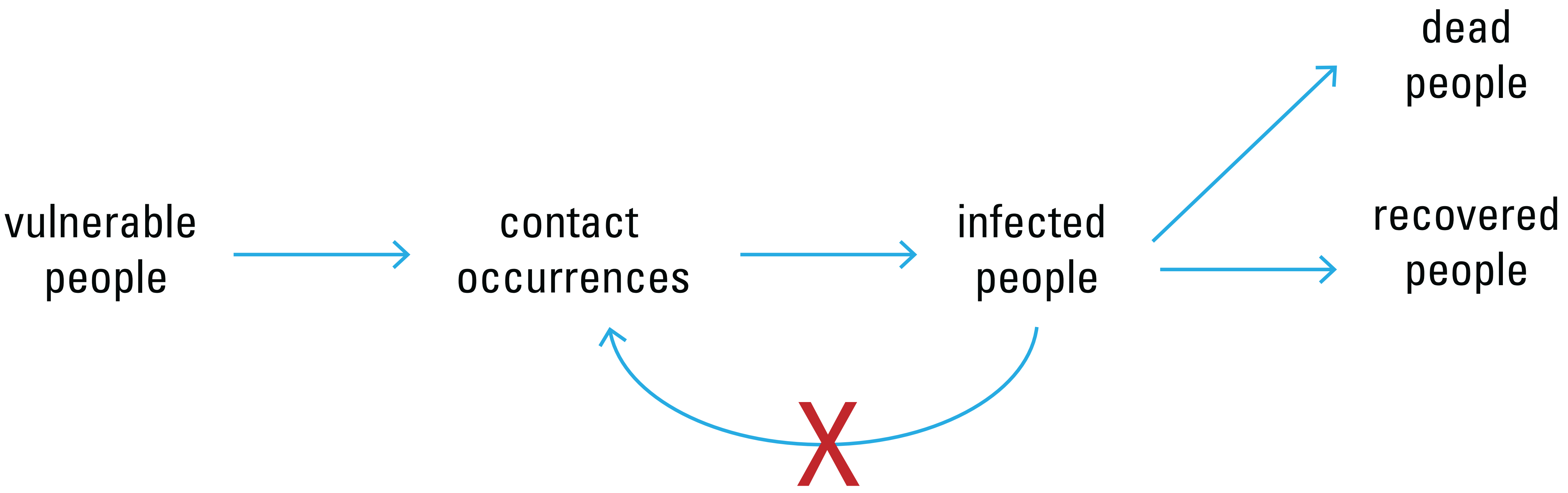
And how do infected people create more infected people?
The answer is mainly by contact.



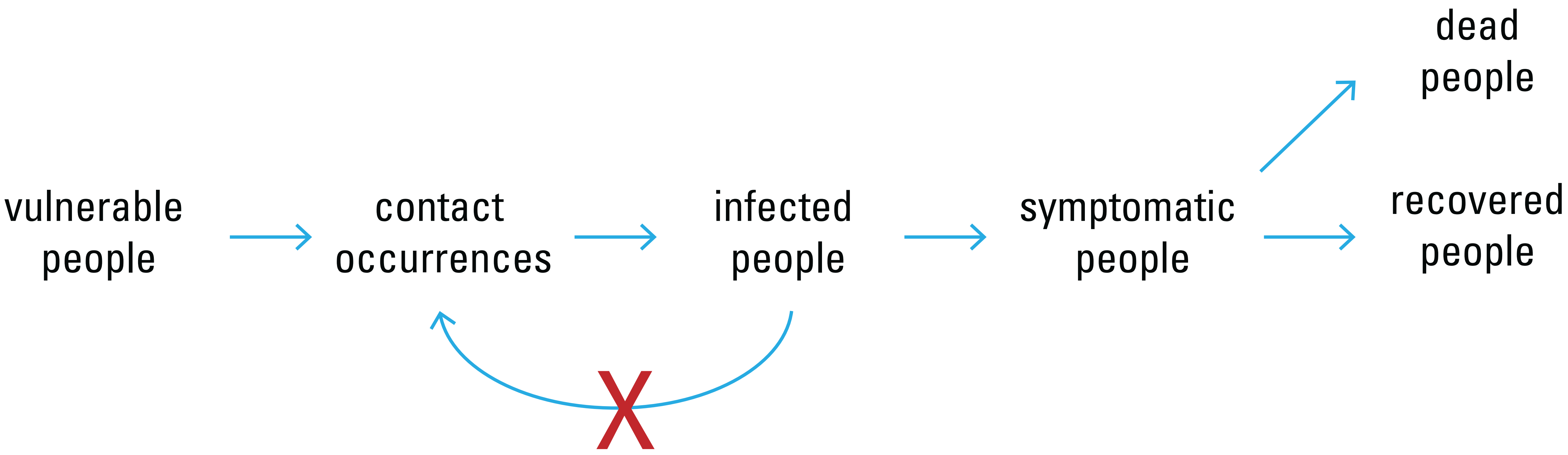
Eventually, infected people recover (hopefully with immunity) or they die.



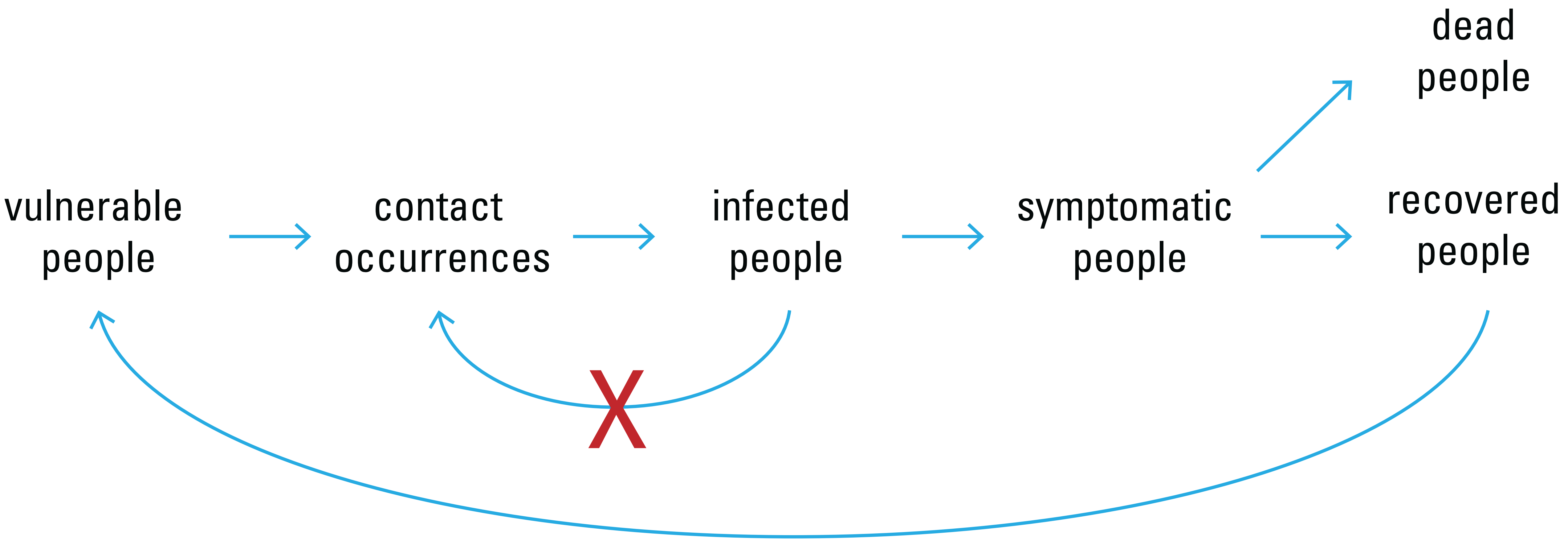
And how might we “flatten the curve” (and reduce deaths)? The answer is mainly by reducing contacts — e.g., quarantining infected people.



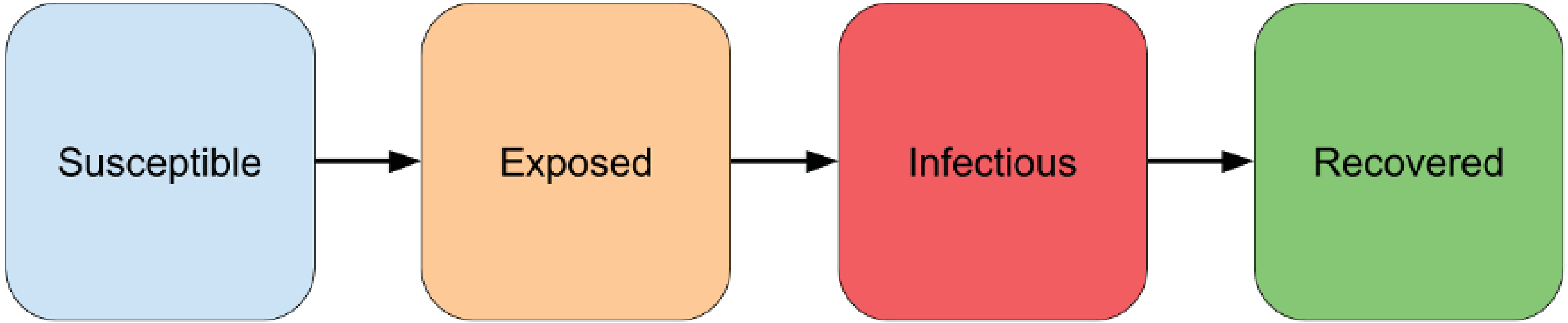
But then why do we “shelter-at-home”? Because it’s not (yet) possible to identify infected people before they start transmitting the disease.



How long will COVID-19 survivors retain immunity?

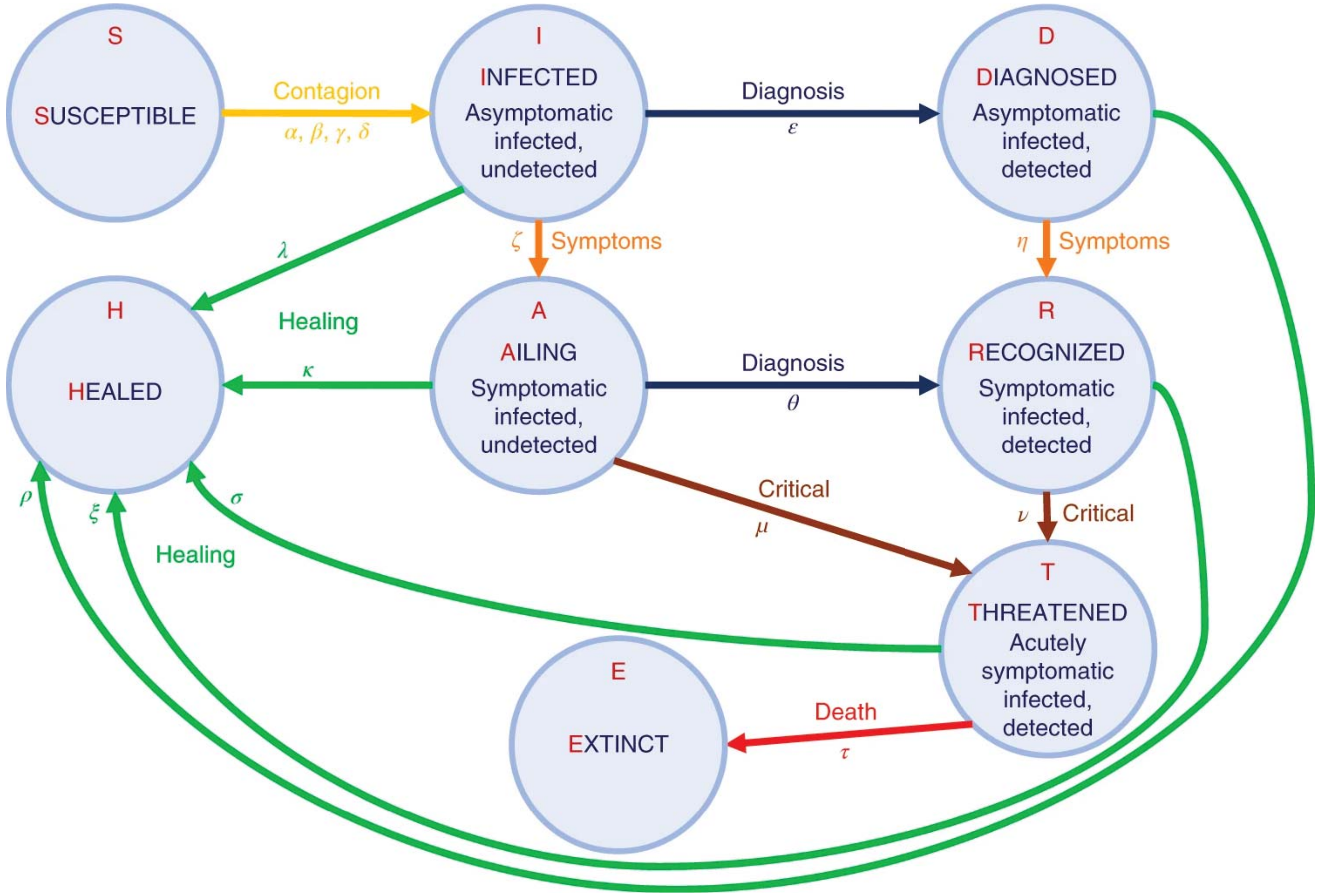


SEIR Model from Epidemiology



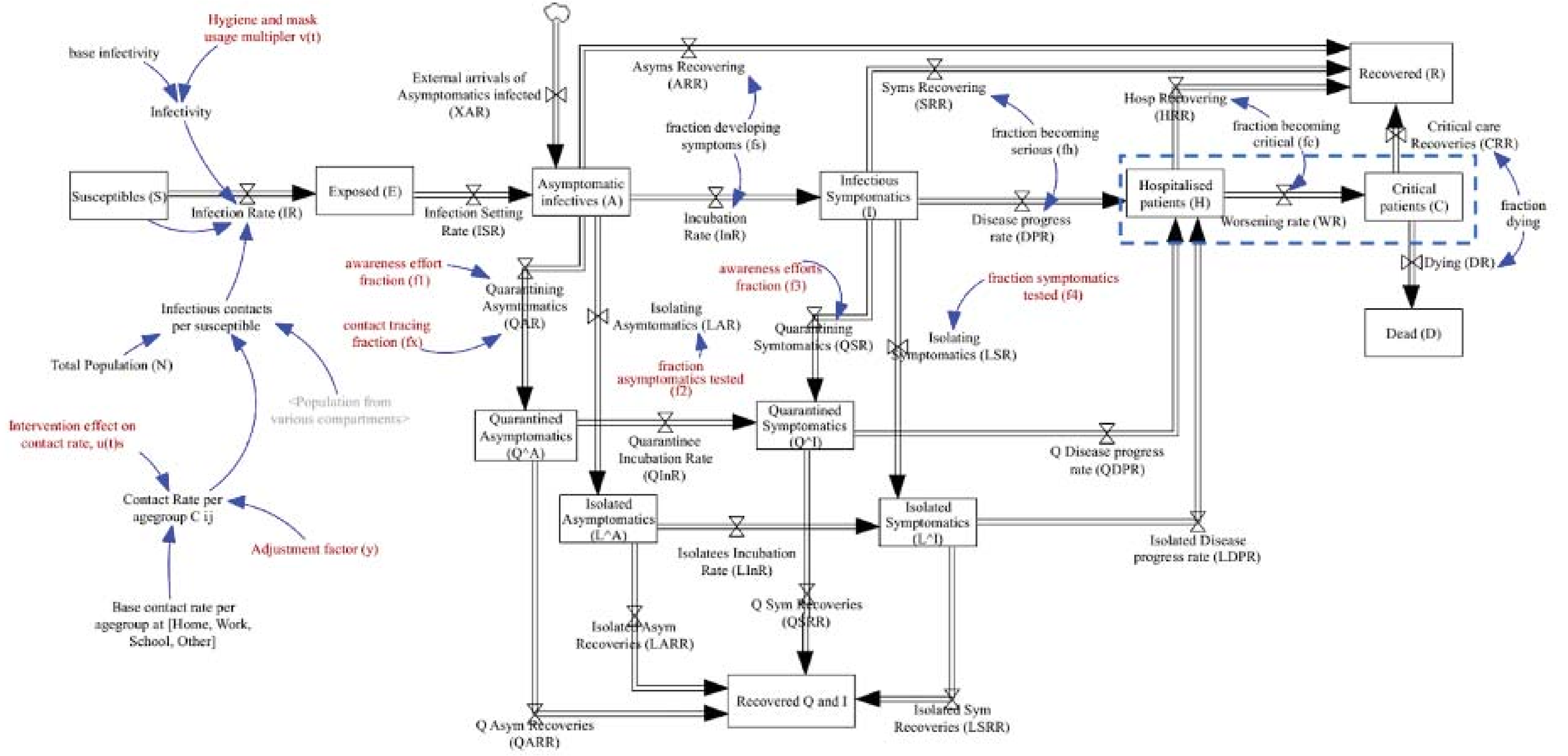
Credit: https://web.stanford.edu/~ashishg/msande433/India_Model/india_model/report.html

Nature-Medicine: “Modeling the COVID-19 epidemic and implementation of population-wide interventions in Italy”



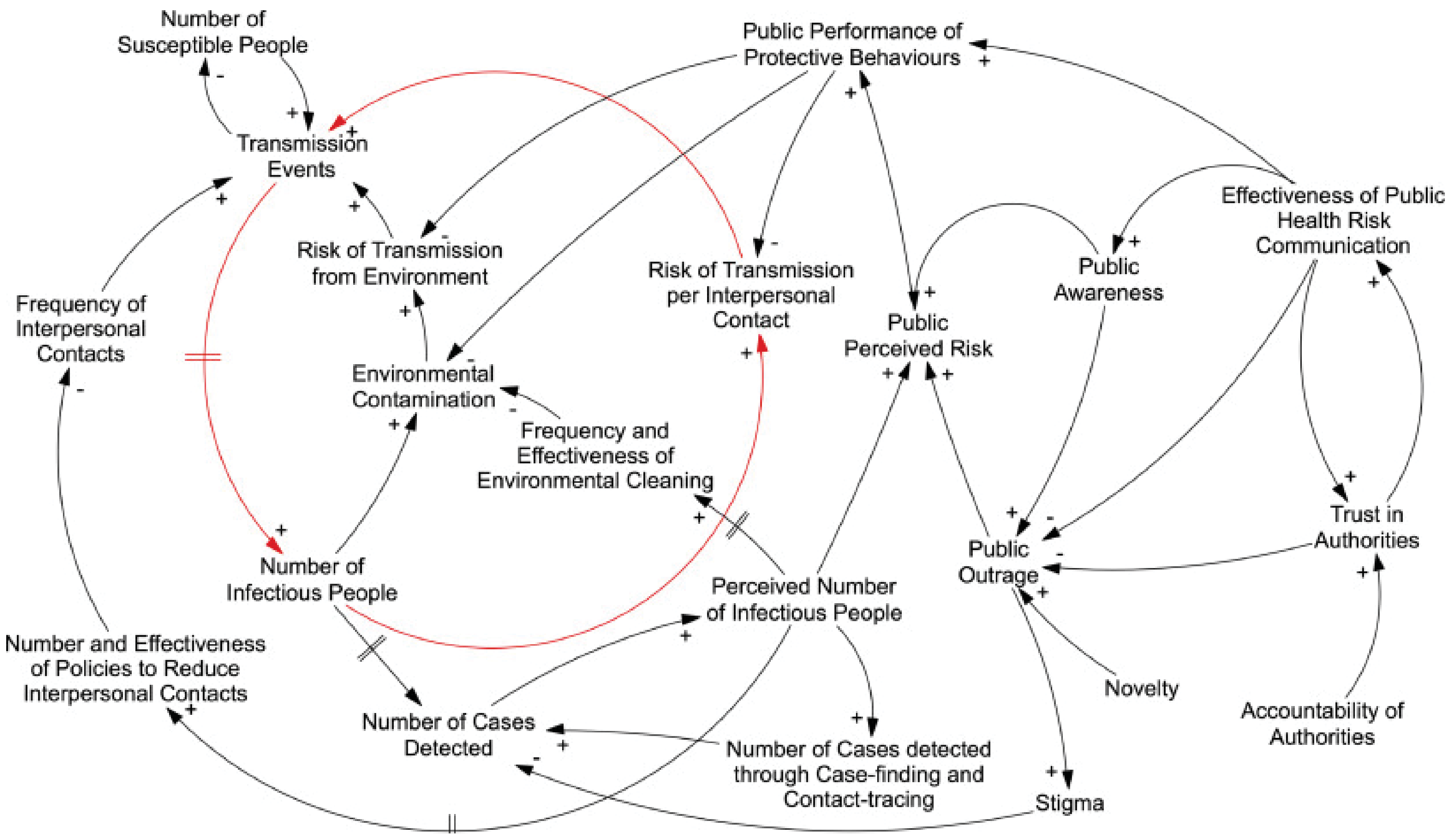
Credit: https://www.nature.com/articles/s41591-020-0883-7/figures/1

Stanford: "A COVID-19 System Dynamics Model for the Indian Government"



Credit: https://web.stanford.edu/~ashishg/msande433/India_Model/india_model/report.html

A model from “The Lancet”: “A systems approach to preventing and responding to COVID-19”



Credit: https://www.thelancet.com/journals/eclinm/article/PIIS2589-5370(20)30069-9/fulltext#articleInformation

Special thanks to

Jamie Ikeda

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Presentation posted at

systems.dubberly.com/systems_dynamics_20200720.pdf