

Part III — Accumulation

What Accumulates

Online, with a lab for each exercise: thinking-in-diagrams.aryehnielsen.com

Stock & flow diagrams

Part III · Accumulation · Chapter 6 of 12 · the first of two chapters on stock & flow diagrams

What would still be there if everything stopped? A stock & flow diagram shows what accumulates, which flows fill and drain it, and which readings set how fast each flow runs.

Signals you need this diagram

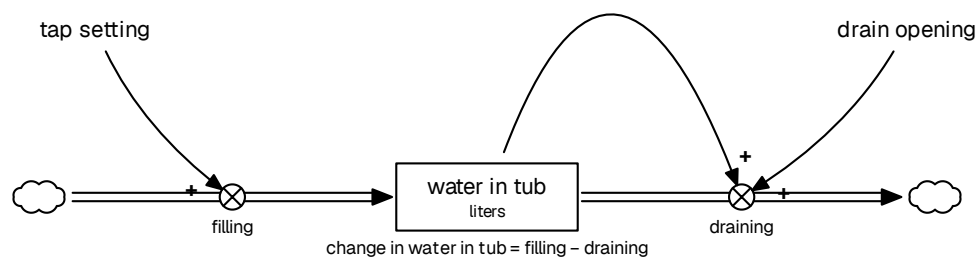
- Something builds up or runs down: savings, a backlog, a population.
- A cut in what comes in hasn't stopped the total rising.
- Something leaves one place and has to turn up in another.
- Amounts have units, and the units have to agree.

A bathtub filling and draining

With the plug in and the tap on, the water in a bathtub rises by the same amount every minute.

With the plug out, it rises more slowly as it deepens, since deeper water drains faster, until it drains as fast as it fills and holds one depth.

Turn off the tap and put the plug in: filling and draining stop, and the water is still there.

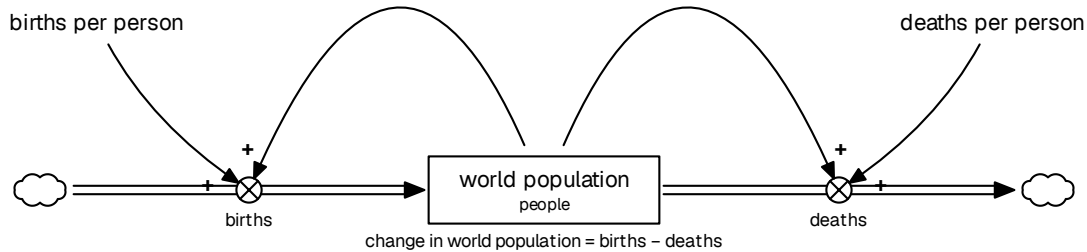


What the notation expresses

Stocks

A **stock** is a quantity that accumulates: what would still be there if every flow stopped. The water in the tub can be measured at an instant; filling and draining exist only over time. A stock changes only through its flows.

It is drawn as a box around its name, its units beneath in smaller type. The world's population is drawn the same way, filled by births and drained by deaths.

**CHECK YOUR UNDERSTANDING**

A phone charges overnight and runs down through the day. Which of these is a stock?

- a the charge in its battery
- b charging
- c the screen's brightness

Feedback: Answers, chapter 6

Flows

A **flow** moves material into or out of a stock. It is drawn as a double line, its **material path**, with an arrowhead where the material goes and, at its middle, a **valve**: a small circle crossed by an X, the flow's name beside it.

A flow into a stock is one of its **inflows**, a flow out of it one of its **outflows**: *filling* is the tub's inflow, *draining* its outflow. A flow's value at an instant is its **rate**, such as 12 liters a minute.

A flow is named for what moves, *filling* or *births*, not for what sets it moving, such as *tap*.

Clouds

A **cloud**, a small unnamed scalloped outline, is where a flow's material comes from or goes to outside the model: the flow's **source** where it starts, its **sink** where it ends. The bathtub's model leaves out the water main and the sewer, so filling starts at a cloud and draining ends at one.

Each cloud ends one flow; whatever you name or count is a stock instead.

Units

Every stock has **units**: liters for the water in the tub, people for the world's population.

A diagram has one **time unit**, the unit every rate is per: the minute for the bathtub, the year for the population. A flow's units are its stock's units per time unit, so filling and draining run in liters per minute.

Transfers

A **transfer** is a flow from one stock straight into another: an outflow of the first and an inflow of the second, such as pouring from *water in bucket* into *water in tub*.

Material that leaves a stock arrives somewhere, in another stock or at a cloud: **conservation**. So both stocks of a transfer count it in the same units, liters for the bucket and the tub.

Auxiliaries

An **auxiliary** is a variable that neither accumulates nor flows, such as a setting, a capacity or a ratio, drawn as its name alone: *tap setting*, *drain opening*, or the population's *births per person*, the year's births divided by the people alive. In Stella, a modeling program, an auxiliary is a *converter*.

Signals

A **signal** is a single thin line with an arrowhead, carrying a reading of one quantity to an auxiliary or to a flow's valve; in the systems literature, an *information link*.

Tap setting → *filling* carries the tap's setting, not water, and has a polarity as chapter 4's effects

thinking-in-diagrams.aryehnielsen.com/feedback/loops-that-amplify-loops-that-correct/#polarity do: +, since the further the tap is open, the faster the tub fills.

+ signals run from *water in tub* to *draining* and from *world population* to *births* and *deaths*. A signal from a stock to one of its own flows closes a loop through that stock (chapter 7

thinking-in-diagrams.aryehnielsen.com/accumulation/stocks-inside-feedback/#loops-through-stocks).

The stock equation

A **stock equation**, one line beneath a stock's box, adds its inflows and subtracts its outflows:

change in water in tub = filling - draining

Its right-hand side is the stock's **net flow**. With filling at 12 liters a minute and draining at 8, the net flow is 4 liters a minute. In 2023 about 132 million people were born worldwide and 62 million died: a net flow of about 70 million people a year.

Auxiliaries and signals never appear in it; they change a stock only through a flow's rate. A stock with no flows reads change in ... = 0.

Delays on flows

A **delay** on a flow, two short strokes across its double line, means its material arrives well after it leaves, as a change arrives late along a delayed effect

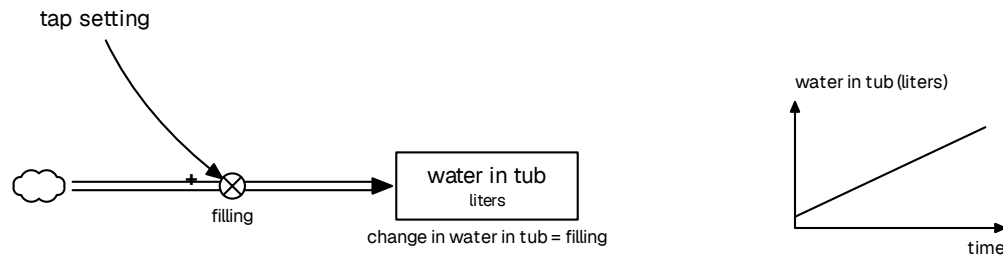
thinking-in-diagrams.aryehnielsen.com/feedback/loops-that-amplify-loops-that-correct/#delays. Grain shipped from a port reaches a mill weeks later: the flow from *grain at the port* to *grain at the mill* carries a delay, and the grain at sea is in neither stock.

Behavior-over-time graphs

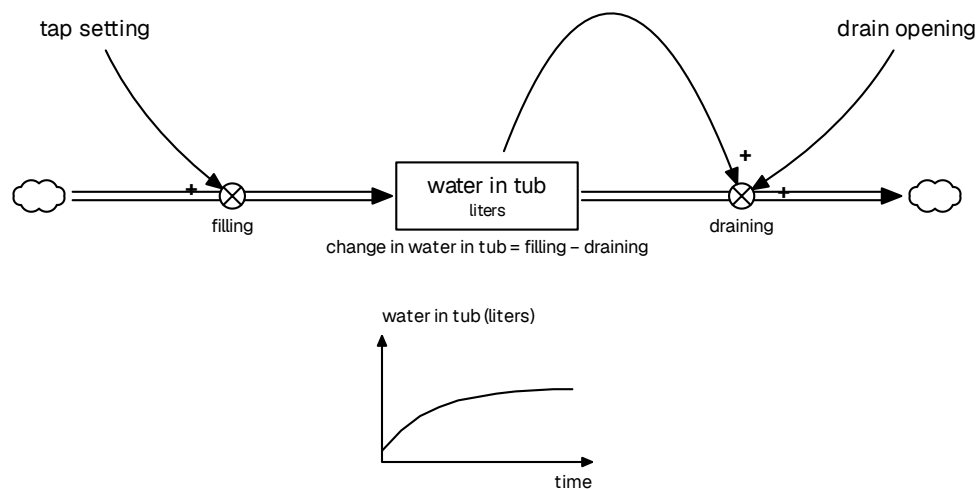
A **behavior-over-time graph** shows one stock, flow or auxiliary over time: the quantity's name (and a stock's units) on the vertical axis, *time* on the horizontal, and one line of a named shape, rising or falling. The shapes are *linear*, *exponential*, *approach* (flattening toward a value), *oscillation* (swinging around a value), *S-shaped* and *overshoot and collapse*. A graph is a prediction from the structure, made before anything is measured.

A stock's slope at any instant is its net flow: it rises while inflows exceed outflows, falls while outflows exceed inflows, and stays flat when they are equal.

With the plug in, the net flow is filling's steady rate, so the water rises in a straight line.



With the plug out, draining speeds up as the water deepens, the net flow shrinks, and the water approaches the depth at which draining equals filling.



Asked to draw the water in a bathtub from graphs of its inflow and outflow, many graduate students at MIT's business school drew a path its flows couldn't produce (Booth Sweeney and Sterman, 2000); chapter 7's *Common misreading* thinking-in-diagrams.aryehnielsen.com/accumulation/stocks-inside-feedback/#common-misreading gives a later study's numbers.

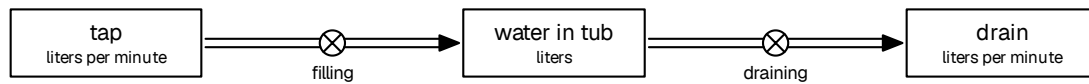
What stays informal

When nothing accumulates, or the question is only which way one quantity moves another, a sentence does: *opening the drain wider empties the tub faster*. With several such effects running in a circle, a causal loop diagram does. When the question is how much there is now, not how it changes, a list of amounts does.

The diagram holds no numbers: rates and amounts go in a sentence or a table beside it.

The bad diagram

What's wrong with this diagram of a bathtub filling from the tap and emptying down the drain?

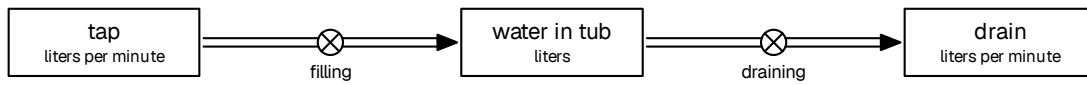
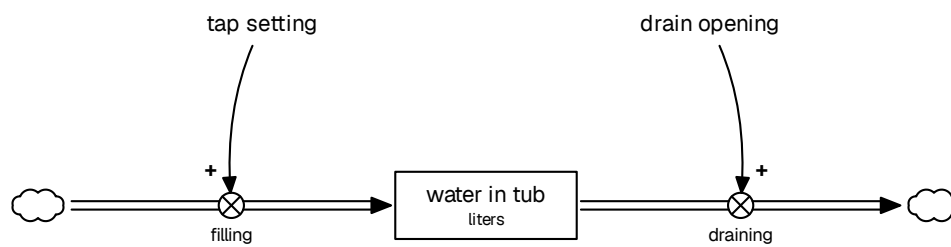


The tap, the water in the tub and the drain are three stocks in a row, joined by filling and draining. The tap is counted in liters per minute and the tub in liters, so filling's units come out as liters per minute per minute. The tap holds no water: its setting fixes how fast filling runs, as the drain's opening fixes draining. The lab's check reports:

2 transfers join stocks in different units: filling, from tap (liters per minute) to water in tub (liters); draining, from water in tub (liters) to drain (liters per minute). What leaves one stock arrives in the other, so both count it in the same units.

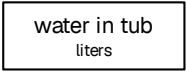
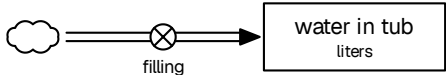
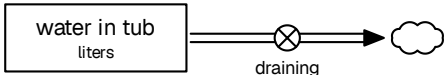
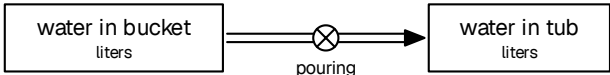
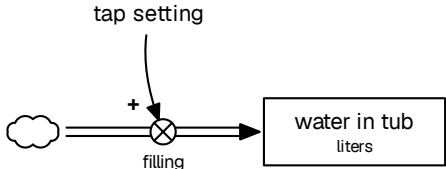
The corrected diagram

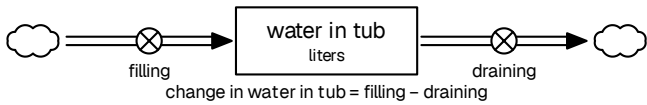
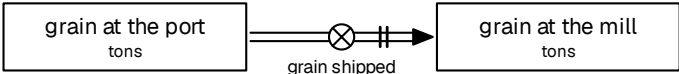
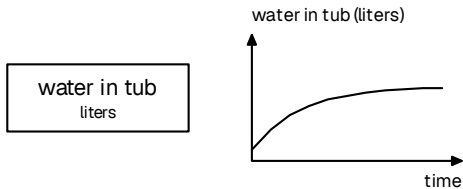
The tap and the drain become auxiliaries, *tap setting* and *drain opening*, each with a + signal to its flow's valve. Filling starts at a cloud and draining ends at one, leaving *water in tub*, in liters, the one stock, and both flows in liters per minute.

Bad diagram**Corrected diagram**

Changed: 2 labels. Stocks: 2 turned into auxiliaries. Flows: filling now starts at a cloud instead of tap, draining now ends at a cloud instead of drain. Signals: 2 added.

Notation moves

Notation move	When	What it shows	Example
Draw a stock, with units	Something would remain if every flow stopped	What accumulates, in what units	<i>water in tub, liters</i>
			
Draw a flow	Material moves into or out of a stock	What moves, which way	<i>filling</i>
			
End a flow at a cloud	Material enters or leaves the model	Where the model stops	<i>draining's sink</i>
			
Declare the time unit		What every rate is per	minute
Draw a transfer	Material moves between stocks	Where it goes, in the same units	<i>water in bucket → water in tub</i>
			
Draw an auxiliary	A setting, target or ratio sets a rate	What a rate depends on	<i>tap setting</i>
tap setting			
Draw a signal to a valve	A reading changes a flow's rate	Which reading, which way	<i>tap setting → filling, +</i>
			

Notation move	When	What it shows	Example
Show the stock equation		The net flow	change in water in tub = filling - draining
			
Mark a delay on a flow	Material arrives well after it leaves	Material in transit	grain shipped to a mill
			
Draw a behavior-over-time graph		The predicted shape	<i>water in tub</i> , approach
			

Check your understanding

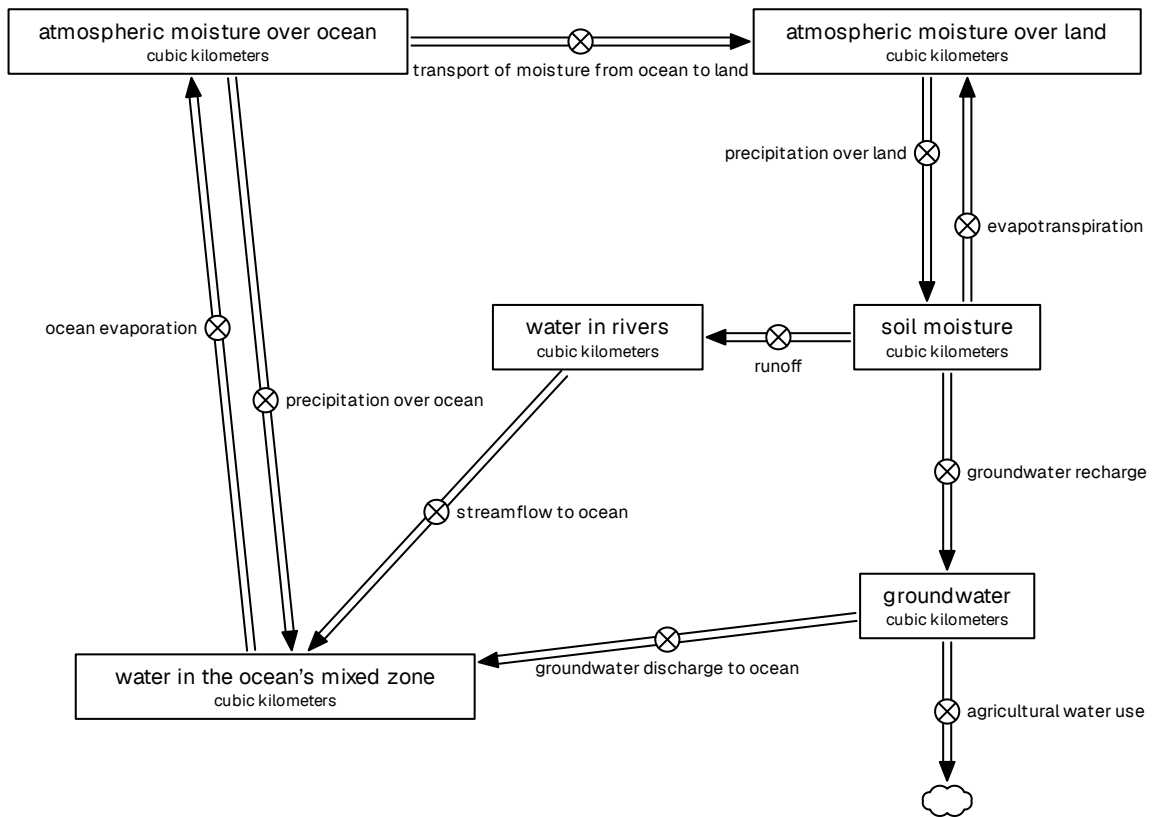
CHECK YOUR UNDERSTANDING

Emails reach Dana's inbox at 60 a day, and she answers or archives 50 a day. This week, arrivals fall to 55 a day while she still clears 50. What do the emails in her inbox do this week?

- a They keep rising, by 5 a day instead of 10
- b They fall, because fewer emails arrive
- c They hold steady

Feedback: Answers, chapter 6

Earth's water, stored and moving, redrawn



Redrawn from U.S. Geological Survey, "The Water Cycle" (2022), also published as Hayley R. Corson-Dosch and others, The water cycle, USGS General Information Product 221 (2023) www.usgs.gov/media/images/water-cycle-png, the diagram, in English. U.S. public domain; credit: U.S. Geological Survey.

Six of its fifteen pools drawn as stocks, the ocean's mixed zone among them and its rivers named as the water in them; ten of its fluxes drawn as flows between them, each given one stock at each end, so precipitation over land ends in soil moisture; of its five kinds of human water use, agricultural water use alone, drawn from groundwater to a cloud; units added, cubic kilometers and a time unit of a year, since it gives no amounts; its pictures and colors left out.

QUESTION 1 OF 3

USGS calls each place water is stored a pool, drawn here as a stock, and each way water moves between pools a flux, drawn as a flow. Which flow is not a transfer?

- a Evapotranspiration, since liquid water leaves the soil as vapor.
- b Agricultural water use, which ends at a cloud.
- c Transport of moisture from ocean to land, since it carries water sideways through the air rather than into or out of the ground or the sea.

QUESTION 2 OF 3

USGS gives no amounts. The redrawing counts every stock in cubic kilometers and declares the year as its time unit. In what units does ocean evaporation run?

- a Cubic kilometers.
- b Millimeters a year, the depth of water lost from the sea's surface.
- c Cubic kilometers a year.

QUESTION 3 OF 3

Which is the stock equation of groundwater?

- a $\text{change in groundwater} = \text{groundwater recharge} - \text{groundwater discharge to ocean} - \text{agricultural water use}$
- b $\text{change in groundwater} = \text{groundwater recharge} - \text{groundwater discharge to ocean}$
- c $\text{change in groundwater} = \text{groundwater recharge} + \text{runoff} - \text{groundwater discharge to ocean}$

Feedback: Answers, chapter 6

Exercises

Passing the checks means meeting the brief, not being right.

SF 01 Words a language learner knows

One stock and one inflow

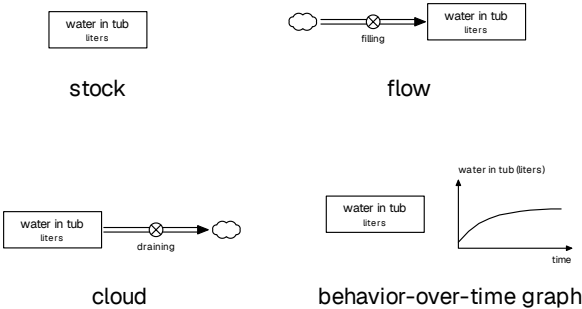
Reasoning ●○○○○ 1 of 5 Polish ●○○○○ 1 of 5

Lena is learning Portuguese from a box of flashcards. She knows about 300 words today and learns about forty new ones a week, a few each evening. Leave forgetting out: draw only the words she knows and the words she learns. Count what she knows in words, and time in weeks.

The brief

- ☐ Draw one stock: the words Lena knows.
- ☐ Fill it with one inflow.
- ☐ Draw one cloud, where the new words come from.
- ☐ Add a behavior-over-time graph of the stock, rising steadily.
- ☐ The stock is counted at an instant, in words; the flow per week, in words per week.

Your palette



Draw here

A large grid of dots for drawing the model.

SF 02 Firewood at a scout camp

Inflow and outflow

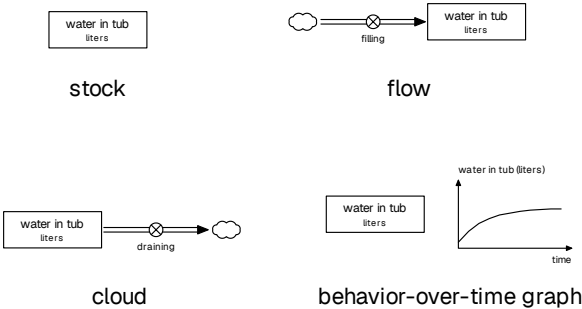
Reasoning ●○○○○ 1 of 5 Polish ●●○○○ 2 of 5

A scout patrol camps in a field for the weekend. Through Saturday afternoon the scouts gather fallen branches into a woodpile by the fire, about thirty kilograms an hour. After dark they gather about five kilograms an hour, and the campfire burns about twelve kilograms an hour. Count the wood in kilograms, and time in hours.

The brief

- ☐ Draw one inflow: the wood the scouts gather.
- ☐ Draw one outflow: the wood the fire burns.
- ☐ Put a cloud at each end, where the wood comes from and where it goes.
- ☐ Add a behavior-over-time graph of the stock, falling steadily.
- ☐ The graph covers the evening, after gathering slows.

Your palette

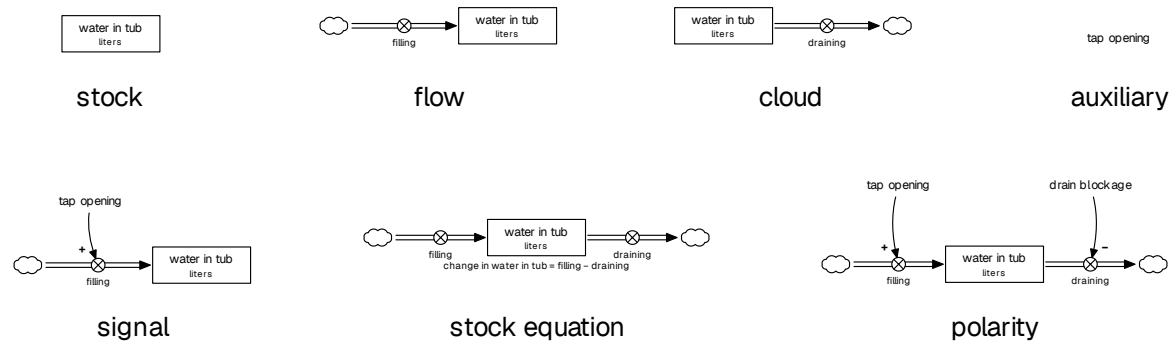


Draw here

A large grid of dots for drawing.

SF 03 Goats on a family smallholding

Your palette



SF 03 Goats on a family smallholding

Net flow and equations

Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

The Mensah family keeps goats on a smallholding: twenty at the start of the year. Each spring the herd has about one kid for every goat in it, so a bigger herd has more kids. Each year the family buys about two goats at market and sells about fifteen. Count the herd in goats, and time in years.

The brief

- ☐ Draw two inflows: kids born, and goats bought.
- ☐ Draw one outflow: goats sold.
- ☐ Add an auxiliary for the kids each goat has in a year.
- ☐ Draw a path of signals from the herd to kids born.
- ☐ Show the herd's stock equation.
- ☐ Kids born reads two signals: one from the herd, one from kids per goat per year.

Your palette

On the page before this sheet.

Draw here

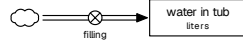
Diagram drawing area with a grid of dots.

SF 04 Diesel for an island's power station

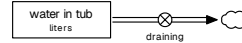
Your palette



stock



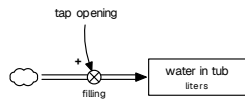
flow



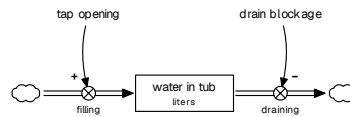
cloud

tap opening

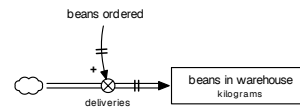
auxiliary



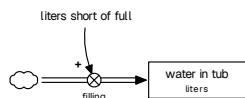
signal



polarity

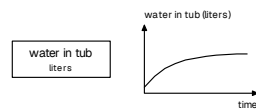


delay



gap

*drawn as an ordinary
variable*



behavior-over-time
graph

SF 05 Bottles in a deposit-return scheme

Connected stocks and conservation

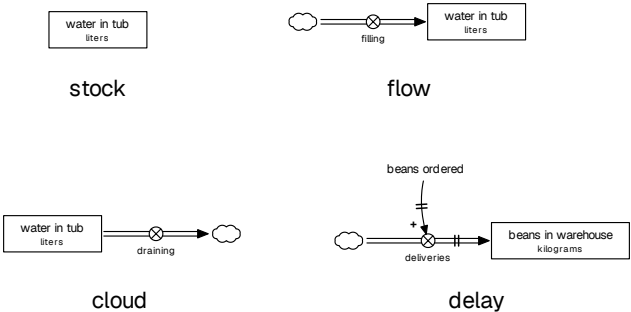
Reasoning ●●●○○ 3 of 5 Polish ●●●○○ 3 of 5

A country runs a deposit-return scheme for drink bottles. Bottlers deliver bottles to shops, where a bottle waits about two weeks on a shelf. A shopper keeps a bottle about five weeks before taking it back to a return machine; about one bottle in ten is thrown away instead. The machines are emptied twice a week, and the bottles collected for recycling. Count every stock in bottles, and time in weeks.

The brief

- ☐ Draw three stocks, one for each place a bottle waits: on shop shelves, with shoppers, in return machines.
- ☐ Join the stocks with transfers, so a bottle leaving one stage arrives in the next.
- ☐ Mark one material delay.
- ☐ The three stocks sit in a row in the order bottles pass through, and the delay is on the flow out of the stage where bottles wait longest.

Your palette



Draw here

A large grid of dots for drawing the diagram.

CS 06 Kelsham Primary School: the roll, filled and drained

One stock, its two flows and the years of the roll

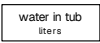
Reasoning ●●○○○ 2 of 5 Polish ●●○○○ 2 of 5

Ruth Okafor counts the pupils on roll each October: 126 in October 2020, 95 in October 2025 and 88 in October 2026. Children start in Reception each September, and pupils leave, Year 6 for secondary school and others for other schools. In the year to October 2026, 9 children started and 16 pupils left; in the year to October 2020, 19 started and 20 left. In every year between, fewer started than left. Count the roll in pupils, and time in years.

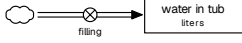
The brief

- ☐ Draw one stock: the pupils on roll, counted in pupils.
- ☐ Fill it with one inflow: the children starting each September.
- ☐ Drain it with one outflow: the pupils leaving.
- ☐ Show the roll's stock equation.
- ☐ Add a behavior-over-time graph of the roll, falling steadily.
- ☐ The stock equation balances for the year to October 2026: 95 pupils, plus 9 starters, less 16 leavers, is 88.

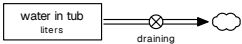
Your palette



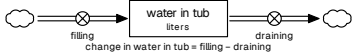
stock



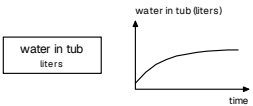
flow



cloud



stock equation



behavior-over-time graph

Draw here

Grid area for drawing diagrams.

Sources

- Donella H. Meadows, *Thinking in Systems: A Primer* (Chelsea Green, 2008), chapter 1, *The Basics*, on stocks, flows, clouds as sources and sinks, and the bathtub.
- John D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin/McGraw-Hill, 2000), chapter 4, *Structure and Behavior of Dynamic Systems*, on the shapes behavior over time takes; chapter 6, *Stocks and Flows*, on the notation and on telling a stock from a flow by freezing a system in time; and chapter 7, *Dynamics of Stocks and Flows*, on reading a stock's path from its net flow.
- Linda Booth Sweeney and John D. Sterman, "Bathtub Dynamics: Initial Results of a Systems Thinking Inventory" doi.org/10.1002/sdr.198, *System Dynamics Review* 16, no. 4 (2000), on how well students with no training in system dynamics read stocks and flows.
- isee systems, *Working with Building Blocks*
iseesystems.com/resources/help/v3/Content/03-BuildingModels/Working_with_building_blocks.htm (Stella help), on the parts of a model in Stella, a modeling program.
- United Nations, *World Population Prospects 2024*, through Our World in Data, *Number of births*
ourworldindata.org/grapher/number-of-births-per-year and *Number of deaths*
ourworldindata.org/grapher/number-of-deaths-per-year, for the world's births and deaths in 2023.

Answers

Chapter 6 · What Accumulates

A phone charges overnight and runs down through the day. Which of these is a stock?

- a the charge in its battery
Yes. Unplug the phone and switch it off, and the charge is still there to be measured, as a percentage of a full battery. Charging fills it and use drains it.
- b charging
Not quite. Charging is a flow: it fills the battery, counted in percent per hour, and it stops when the phone is unplugged. What it leaves behind, the charge, is the stock.
- c the screen's brightness
Not quite. Brightness is an auxiliary: a setting that changes how fast use drains the battery. Nothing builds up in it, so it is drawn as a name with a signal to the valve of the battery's outflow.

Emails reach Dana's inbox at 60 a day, and she answers or archives 50 a day. This week, arrivals fall to 55 a day while she still clears 50. What do the emails in her inbox do this week?

- a They keep rising, by 5 a day instead of 10
Yes. change in emails in inbox = emails arriving – emails cleared: 55 – 50, so the net flow is 5 a day. The inflow fell but still exceeds the outflow, so the stock rises, more slowly.
- b They fall, because fewer emails arrive
Not quite. Fewer arrive than last week, but more still arrive than leave. The inbox falls only once arrivals drop below the 50 a day she clears.
- c They hold steady
Not quite. The inbox holds steady only while arrivals equal clearing, 50 a day each. At 55 in and 50 out, it holds 5 more emails each evening than the evening before.

QUESTION 1 OF 3

USGS calls each place water is stored a pool, drawn here as a stock, and each way water moves between pools a flux, drawn as a flow. Which flow is not a transfer?

- a Evapotranspiration, since liquid water leaves the soil as vapor.
Not quite. The water changes state on the way, but it leaves soil moisture and arrives in atmospheric moisture over land, both stocks counted in cubic kilometers: a transfer.
- b Agricultural water use, which ends at a cloud.
Yes. A transfer runs from one stock straight into another. Agricultural water use leaves groundwater for a cloud: the irrigated fields, and wherever their water goes next, lie outside the model.
- c Transport of moisture from ocean to land, since it carries water sideways through the air rather than into or out of the ground or the sea.
Not quite. It drains atmospheric moisture over ocean and fills atmospheric moisture over land. Air holds stocks as the sea does, so a flow between two of them is a transfer.

QUESTION 2 OF 3

USGS gives no amounts. The redrawing counts every stock in cubic kilometers and declares the year as its time unit. In what units does ocean evaporation run?

a Cubic kilometers.

Not quite. Those are the units of the two stocks it joins, the ocean's mixed zone and atmospheric moisture over ocean. A flow is counted per time unit.

b Millimeters a year, the depth of water lost from the sea's surface.

Not quite. A depth a year is one way to report evaporation, but a flow moves material between stocks, so it runs in their units per time unit, not in units of its own.

c Cubic kilometers a year.

Yes. A flow's units are its stock's units per time unit. Ocean evaporation is a transfer, so the stock it drains and the stock it fills both count what it moves in cubic kilometers.

QUESTION 3 OF 3

Which is the stock equation of groundwater?

a $\text{change in groundwater} = \text{groundwater recharge} - \text{groundwater discharge to ocean} - \text{agricultural water use}$

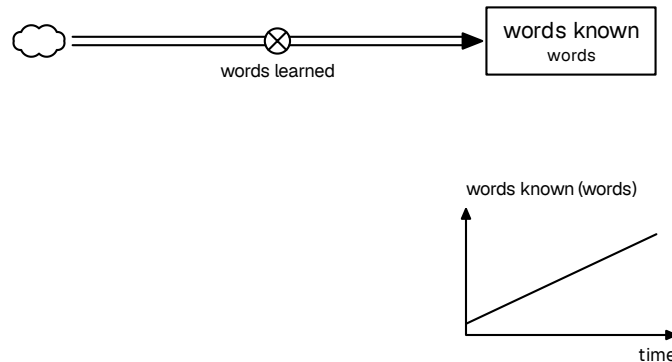
Yes. Groundwater recharge is its one inflow; groundwater discharge to ocean and agricultural water use are its two outflows. Every flow into or out of the stock appears, the one to a cloud as much as the transfers.

b $\text{change in groundwater} = \text{groundwater recharge} - \text{groundwater discharge to ocean}$

Not quite. That leaves out agricultural water use, which drains groundwater too. A flow ending at a cloud still changes the stock it leaves.

c $\text{change in groundwater} = \text{groundwater recharge} + \text{runoff} - \text{groundwater discharge to ocean}$

Not quite. Runoff leaves soil moisture for the water in rivers and never reaches groundwater, so it belongs in those two stocks' equations, not this one.

SF 01 Words a language learner knows

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, words known, counted in words, filled from a cloud by one flow, words learned. The time unit is a week, so words learned is counted in words per week. Nothing drains the stock and about forty words arrive each week, so the graph of words known rises steadily.

Why it works

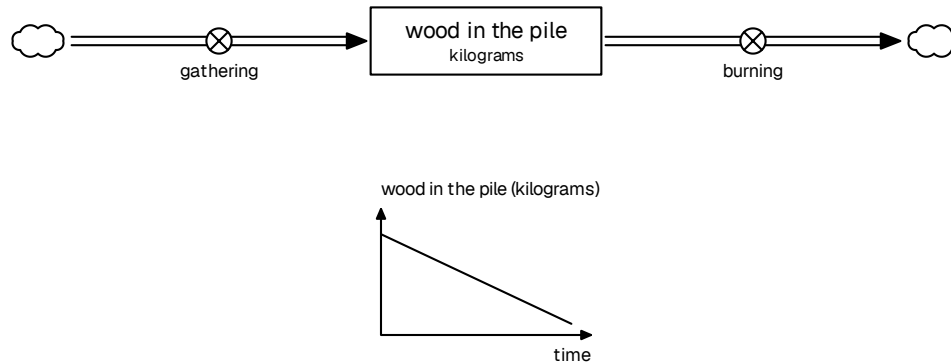
- Words known is the stock: it could be counted on any day, and would still be there if Lena stopped studying
- Words learned is the flow that fills it, counted in words per week
- The cloud is where new words come from, outside what the model holds
- Forgetting is left out, so the graph rises in a straight line

Step by step

1. Words known, the stock, counted in words, with the time unit a week: about 300 words today, the count that the flow fills and the graph follows.
2. Words learned, the flow that fills the stock, drawn with its cloud, since a flow has an end on each side: the words Lena has yet to meet lie outside what the model counts.
3. A behavior-over-time graph of words known, rising in a straight line: forty words a week arrive, and with forgetting left out, none leave.

What another defensible answer might vary

Another defensible answer might name the stock Portuguese words known, or the flow new words learned. What stays the same is one stock with its units, one inflow from one cloud, the time unit a week, and a graph that rises steadily.

SF 02 Firewood at a scout camp

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, wood in the pile, counted in kilograms, filled from a cloud by gathering and drained to another by burning. The time unit is an hour, so both flows are counted in kilograms per hour. After dark the fire burns about twelve kilograms an hour and the scouts gather about five, so the pile falls by about seven kilograms an hour: a straight line down.

Why it works

- The pile is the stock: it could be weighed at any moment
- The pile changes only through gathering and burning
- One cloud for the branches still lying in the field, one for the smoke and ash: both outside what the model holds
- The graph covers the evening, when burning outpaces gathering by a steady seven kilograms an hour

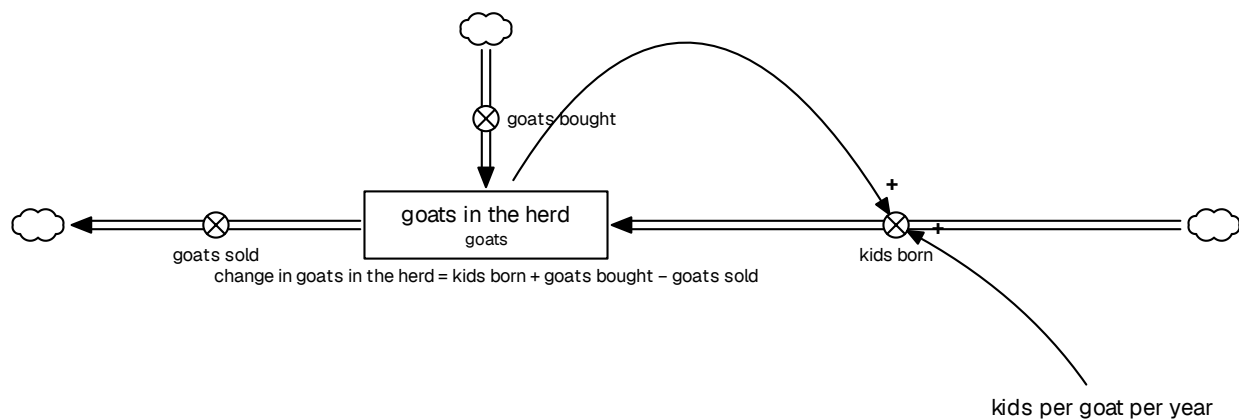
Step by step

1. Wood in the pile, the stock, counted in kilograms, with the time unit an hour: the branches the scouts gather wait here until the fire burns them.
2. Gathering, the inflow, with a cloud at its start, since a fallen branch counts only once it reaches the pile: about thirty kilograms an hour in the afternoon, five after dark.
3. Burning, the outflow, with a cloud at its end for what leaves the fire: about twelve kilograms an hour.
4. A behavior-over-time graph of the pile through the evening, falling in a straight line: twelve kilograms burned against five gathered leaves the pile seven kilograms lighter each hour.

What another defensible answer might vary

Another defensible answer might count the wood in logs, or name the flows wood gathered and wood burned. What stays the same is one stock, one inflow and one outflow, a cloud at each end, the time unit an hour, and a graph that falls steadily.

SF 03 Goats on a family smallholding



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, goats in the herd, counted in goats, filled by kids born and goats bought and drained by goats sold, each flow with a cloud at its other end. The time unit is a year. Signals from the herd and from kids per goat per year, an auxiliary, end at the valve of kids born, both +: a bigger herd has more kids. The stock equation reads $\text{change in goats in the herd} = \text{kids born} + \text{goats bought} - \text{goats sold}$.

Why it works

- Goats in the herd is the one stock: it could be counted on any day
- Kids born, goats bought and goats sold are its flows, each counted in goats per year
- Kids per goat per year is an auxiliary: it holds nothing and moves nothing
- The signal from the herd ends at the valve of kids born, not at the stock: the herd changes only through its flows
- The stock equation is written out from the three flows

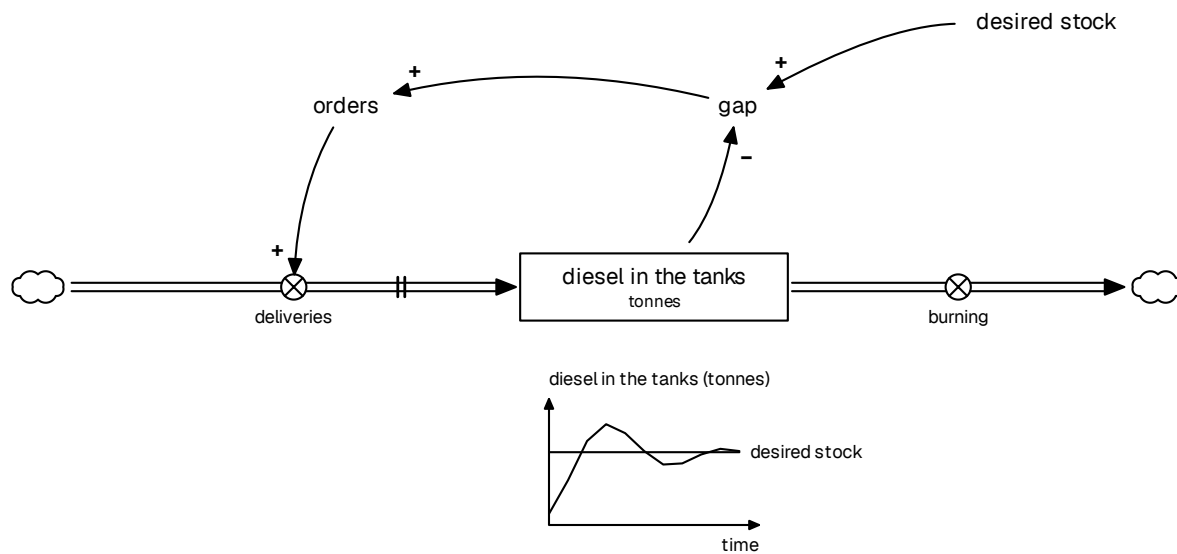
Step by step

1. Goats in the herd, the stock, counted in goats, with the time unit a year and its stock equation beneath it, which gains a term with each flow drawn: twenty goats at the start of the year.
2. Kids born, an inflow from a cloud, since a kid enters the count only when it is born.
3. Goats bought and goats sold, an inflow from a cloud for the market and an outflow to a cloud for the buyers: about two in and fifteen out each year, the last terms of the stock equation.
4. Kids per goat per year, an auxiliary, and + signals from it and from the herd to the valve of kids born: twenty goats with about one kid each bring about twenty kids a spring, and forty bring forty.

What another defensible answer might vary

Another defensible answer might put a second auxiliary, does in the herd, between the herd and kids born, or name the flows births, purchases and sales. What stays the same is one stock with two inflows and one outflow, a path of signals from the herd to kids born, and the stock equation shown.

SF 04 Diesel for an island's power station



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, diesel in the tanks, counted in tonnes, filled from a cloud by deliveries and drained to another by burning; the time unit is a week. Signals run from the stock (–) and from desired stock (+) to the gap, from the gap to orders (+), and from orders to the valve of deliveries (+). Deliveries carry a material delay: each order arrives four weeks after it is placed. Orders keep rising while the ordered diesel is still at sea, so the tanks rise past 250 tonnes to about 340, fall back to about 190, and swing closer each time: the graph oscillates around the line at desired stock.

Why it works

- Orders are an auxiliary: an order placed moves no diesel until its tanker arrives
- Deliveries are the flow, and the four weeks are a material delay on it
- The gap reads the stock and desired stock, and sets orders
- The path from the stock to deliveries ends at the flow's valve: the tanks change only through their flows
- The graph's line is drawn at the desired stock auxiliary, solid

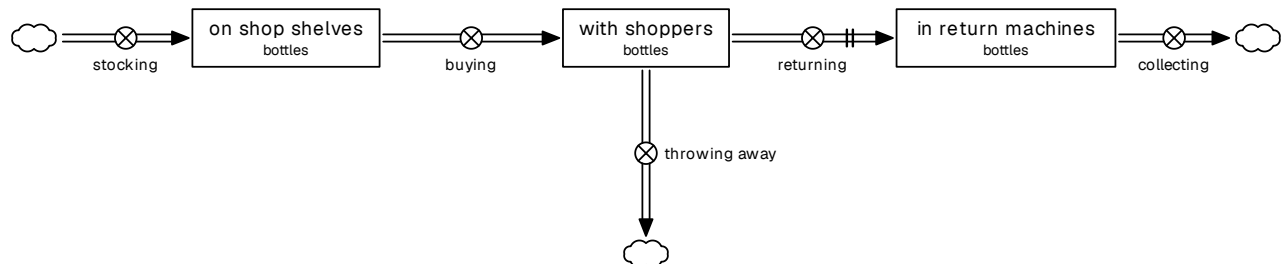
Step by step

1. Diesel in the tanks, the stock, counted in tonnes, with the time unit a week: 100 tonnes after the storms, against the 250 the manager aims to keep.
2. Burning, the outflow to a cloud: the power station burns about 40 tonnes a week, whatever the tanks hold.
3. Deliveries, the inflow from a cloud, with a material delay, since a tanker brings each order four weeks after the manager places it.
4. Desired stock and the gap, two auxiliaries, with a + signal from desired stock and a – signal from the tanks into the gap: the lower the tanks run below 250 tonnes, the larger the gap.
5. Orders, an auxiliary, with a + signal from the gap and a + signal to the valve of deliveries: each week's order is 40 tonnes plus a quarter of the gap, and its diesel reaches the tanks only through deliveries.
6. A behavior-over-time graph of the tanks, with a solid line at desired stock: with four weeks of orders still at sea when the tanks reach 250 tonnes, they rise on to about 340, fall to about 190, and swing closer each time.

What another defensible answer might vary

Another defensible answer might add a signal from burning to orders, for the 40 tonnes ordered each week, or name the stock fuel stock. What stays the same is orders as an auxiliary, deliveries as the flow with one material delay, a path of signals from the stock through the gap to deliveries, and an oscillating graph with its line at the desired stock.

SF 05 Bottles in a deposit-return scheme



This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

Three stocks in a row, each counted in bottles: on shop shelves, with shoppers, in return machines. Stocking fills the shelves from a cloud; buying and returning are transfers, so a bottle leaving one stock arrives in the next; throwing away drains the shoppers' stock to a cloud, and collecting drains the machines to another. The time unit is a week. Bottles wait longest with shoppers, about five weeks, so the material delay is on returning.

Why it works

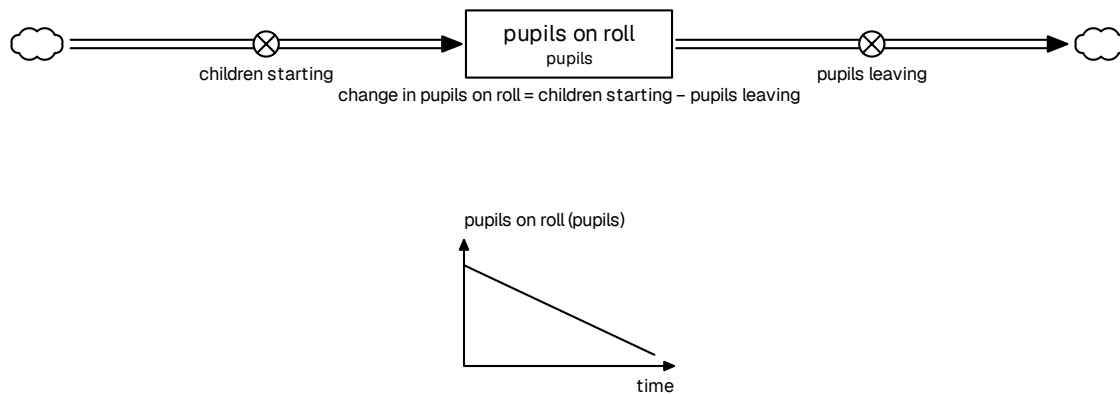
- Each stock is a place where bottles could be counted at an instant
- Buying and returning run from stock to stock, so no bottle appears or vanishes between stages
- Every stock is counted in bottles, so both transfers keep their units
- Throwing away and collecting end at clouds: where a bottle goes after the bin or the recycling lorry lies outside the model
- One delay, on returning: about five weeks with shoppers, against two on a shelf and half a week in a machine

Step by step

1. Three stocks in a row, each counted in bottles, with the time unit a week, in the order a bottle passes through them: on shop shelves, with shoppers, in return machines.
2. Stocking, the inflow to the shelves, from a cloud: a bottle enters the count when the bottlers deliver it to a shop.
3. Buying and returning, two transfers, each from one stock into the next, returning with the material delay: a shopper keeps a bottle about five weeks, longer than it waits anywhere else.
4. Throwing away, out of the shoppers' stock, and collecting, out of the machines, each to a cloud: about one bottle in ten goes in a bin, and the machines are emptied twice a week.

What another defensible answer might vary

Another defensible answer might add a flow from the shelves to a cloud for bottles broken in shops, or name the stocks bottles on sale, bottles at home and bottles awaiting collection. What stays the same is three stocks in bottles in a row, transfers between them, bottles thrown away to a cloud, and one material delay, on returning.

CS 06 Kelsham Primary School: the roll, filled and drained

This is one defensible answer, not the only one. Yours can differ and still hold up: the lab's checks show whether it has the brief's structure.

One stock, pupils on roll, counted in pupils, filled from a cloud by children starting and drained to a cloud by pupils leaving, both in pupils per year. The time unit is a year, and the stock equation reads $\text{change in pupils on roll} = \text{children starting} - \text{pupils leaving}$: in the year to October 2026, $9 - 16$, taking the roll from 95 to 88. Every year from 2020 more pupils left than started, so the graph of the roll falls, from 126 to 88.

Why it works

- Pupils on roll is the stock: it could be counted on any day, and the October count is one such count
- Children starting and pupils leaving are its flows, each counted in pupils per year
- The two clouds are the villages' children not yet at school and the schools pupils leave for, outside what the model counts
- Each October's roll is the last one's plus its starters less its leavers, so the stock equation balances in every year the counts give
- The graph falls because leaving runs above starting every year, though both flows fall

Step by step

1. Pupils on roll, the stock, counted in pupils, with the time unit a year and its stock equation beneath it, which gains a term with each flow drawn: 126 pupils in October 2020.
2. Children starting, an inflow from a cloud, since a child enters the count only in the September they start in Reception: 9 in the year to October 2026.
3. Pupils leaving, an outflow to a cloud for secondary schools and other schools: 16 in the year to October 2026, so the equation takes 95 pupils to 88.
4. A behavior-over-time graph of pupils on roll, falling close to a straight line from 126 to 88: in every year more pupils left than started.

What another defensible answer might vary

Another defensible answer might draw two outflows, Year 6 leaving for secondary school and pupils moving to other schools, or name the inflow starters. What stays the same is one stock in pupils filled by the children starting and drained by those leaving, the time unit a year, the stock equation shown, and a graph of the roll falling.