

Bathtub Dynamics: An Introduction to Stocks and Flows



Students graph water flowing into and out of a bathtub to understand stocks and flows in a system.

Objectives

- After completing this exercise, students will be able to
- describe the difference between stocks and flows of a system, explain how the relationship between flows affects the stock of a system, and
 - use their understanding of stocks and flows to support their positions regarding when and how we should address climate change.

Materials

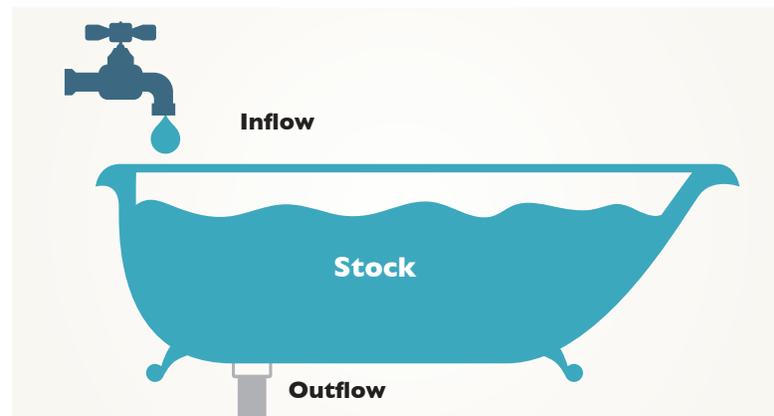
- Bathtub Dynamics and Climate Change presentation and Graphing Stocks student page

Background

In 2000, Linda Booth Sweeney and John Sterman published the results of an experiment they conducted on how people understand complex systems¹. They chose to focus on a system that is familiar to a general audience: a bathtub. Participants in this study included graduate students from Massachusetts Institute of Technology (MIT) and Harvard University. Booth Sweeney and Sterman demonstrated that even highly educated individuals can exhibit fundamental misunderstandings of the concept of stocks and flows in complex systems.

Doing the Exercise

1. In this exercise, students attempt a task similar to the one Booth Sweeney and Sterman gave their participants. If you have advanced students, you may consider starting with the challenge that Booth Sweeney and Sterman used, which is the set of inflows and outflows



shown in the fourth set of graphs on the student page. The proportion of students who draw the correct graph will likely be quite low, but it may be beneficial for students to fail in this way, initially, in order to appreciate the insight they will have gained by the end of the exercise.

2. If you are concerned that such difficulty would cause your students to lose interest, then begin this exercise with the Bathtub Dynamics and Climate Change presentation to introduce the concepts of stocks and flows.

A bathtub can simulate the climate system with the water representing the amount of carbon dioxide flowing into and out of the atmosphere.

3. Once students understand net flow, distribute the Graphing Stocks student page and ask them to work through the four graphs on the student page, which progress from easy to difficult, and the discussion questions.

¹Booth Sweeney, L. & Sterman, J. D. (2000). Bathtub Dynamics: Initial Results of a Systems Thinking Inventory. *System Dynamics Review*, 16, 249-294.



Bathtub Dynamics:
Graphing Stocks (1 of 4)

NAME _____

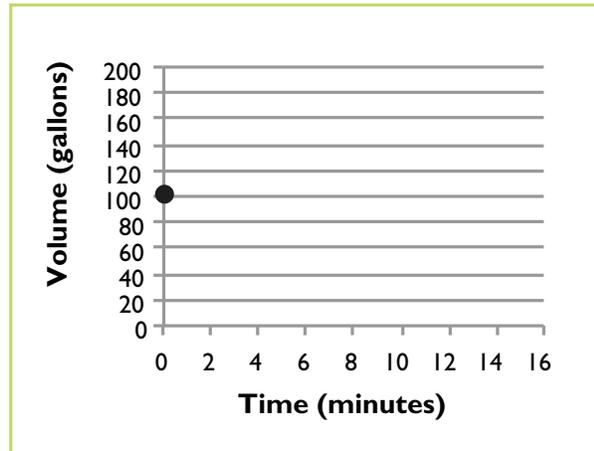
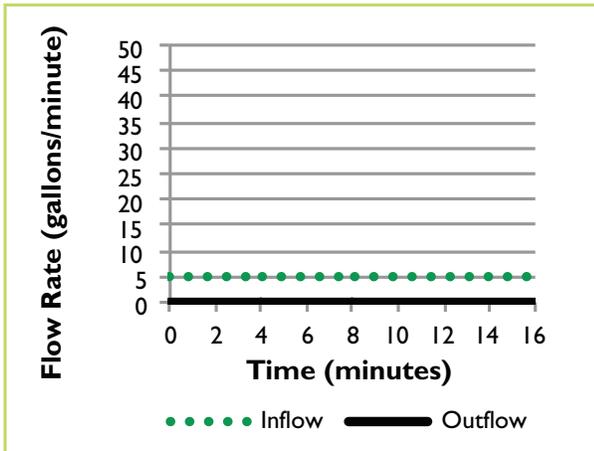
DATE _____

Each graph on the left indicates the rate at which water is entering and leaving the bathtub over time. Use the information shown in these graphs to plot the change in the volume of water over time on the graphs to the right. Assume that the tub always starts with 100 gallons of water (the black dot at minute zero). Then answer the questions that follow the graphs. For example, in Graph 1, the inflow stays steady at 5 gallons a minute for 16 minutes. There is no outflow. What is happening in the bathtub? Draw the level of water in the graph on the right.

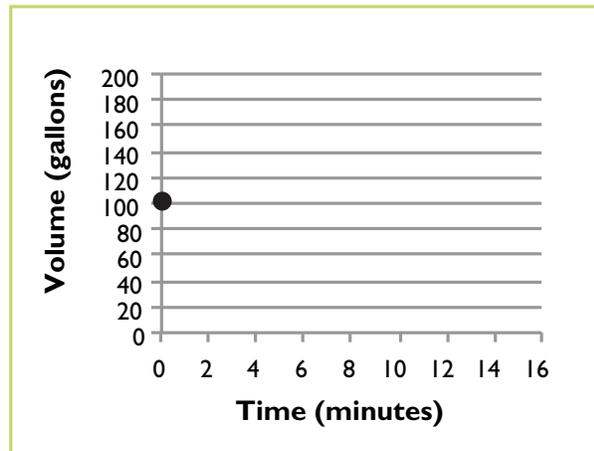
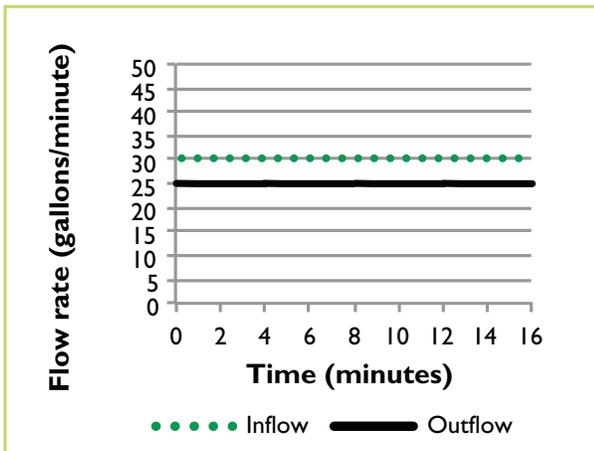
Inflow/Outflow Graphs

Volume in Bathtub

1.



2.



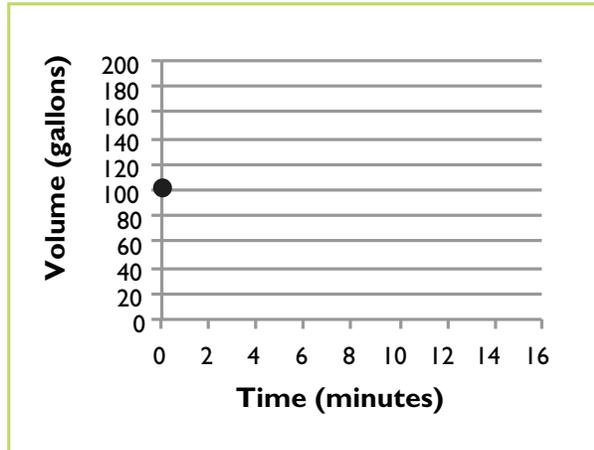
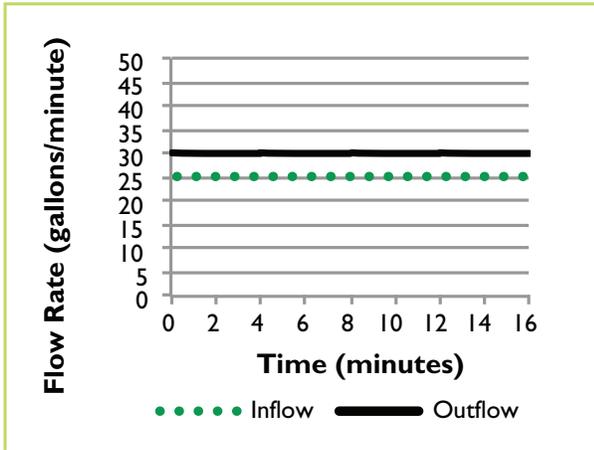


Bathtub Dynamics:
Graphing Stocks (2 of 4)

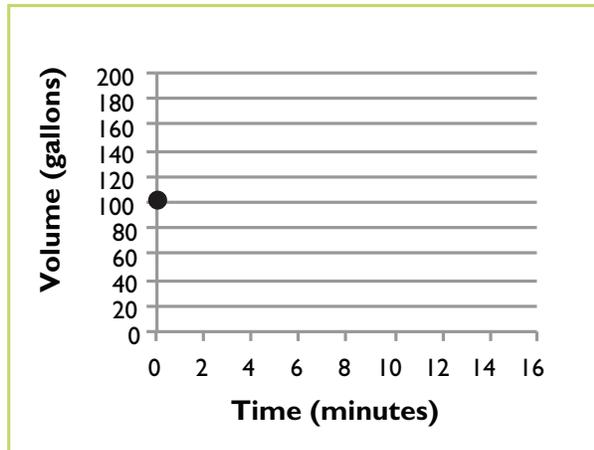
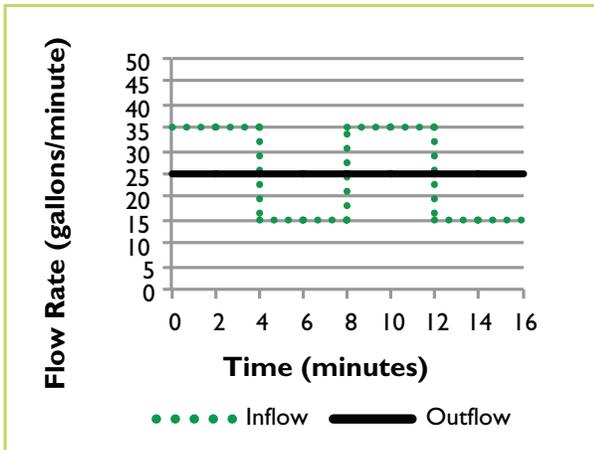
Inflow/Outflow Graphs

Volume in Bathtub

3.



4.



**Bathtub Dynamics****Graphing Stocks** (1 of 3)

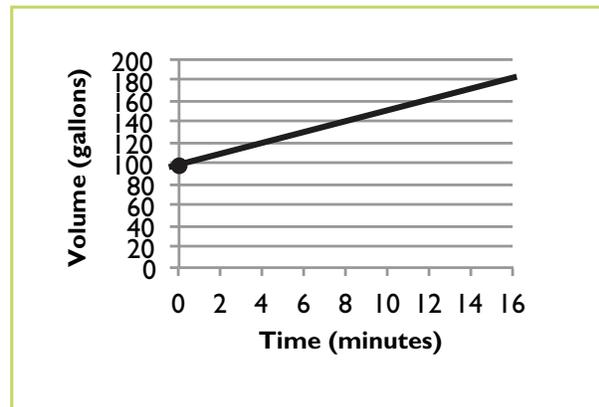
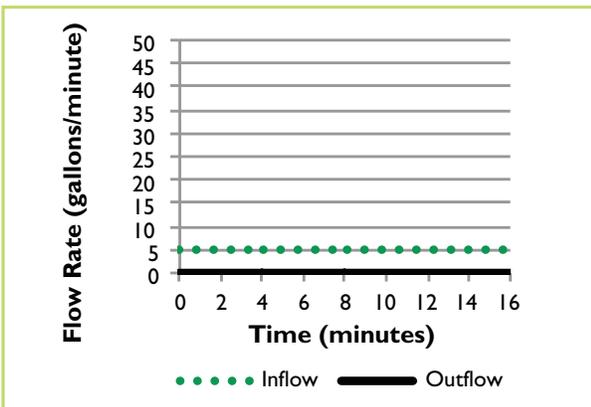
1. The key to all of these problems is calculating the net flow—the difference between the inflow and the outflow. In this first problem, the outflow is 0, so our net flow equation looks like this:

$$\text{Net flow} = 5 \text{ gallons/minute} - 0 \text{ gallons/minute} = 5 \text{ gallons/minute}$$

Both the inflow and the outflow are constant, so the net flow is 5 gallons/minute for the entire 16 minutes. To calculate the change in volume over that time, we can multiply the net flow by the time like this:

$$\text{Change in volume} = 5 \text{ gallons/minute} * 16 \text{ minutes} = 80 \text{ gallons}$$

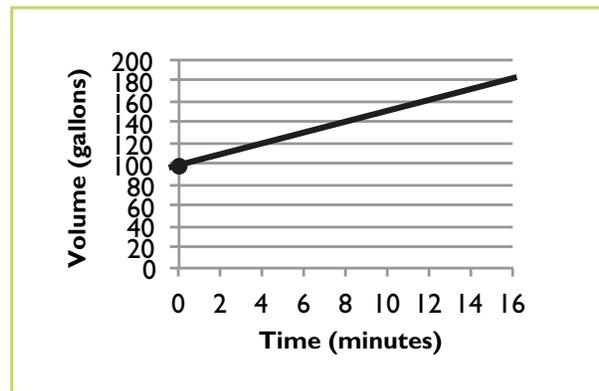
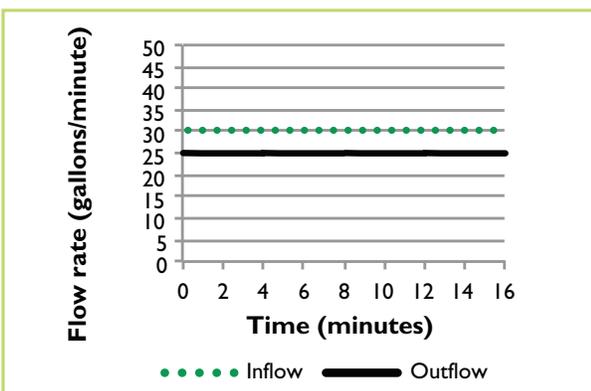
Since we started with 100 gallons, the volume increases to 180 gallons by the end of the 16 minutes.



2. In this problem, the net flow equation looks like this:

$$\text{Net flow} = 30 \text{ gallons/minute} - 25 \text{ gallons/minute} = 5 \text{ gallons/minute}$$

Notice that the net flow is the same as in problem 1. Therefore, the graph of the change in volume will be the same as in problem 1.

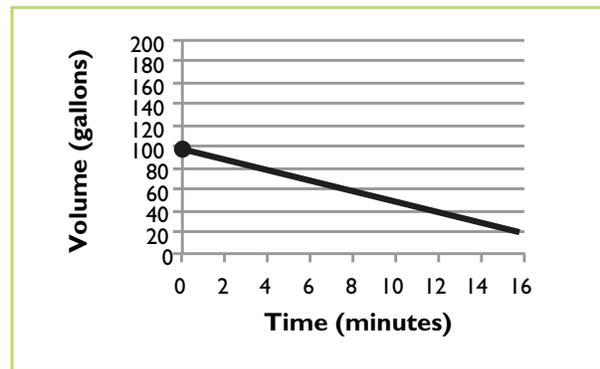
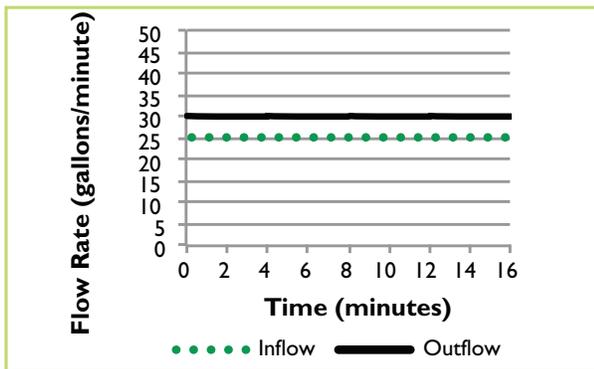


**Bathtub Dynamics****Graphing Stocks** (2 of 3)

3. In the third problem, we have an inflow of 25 gallons/minute and an outflow of 30 gallons/minute. So, the net flow equation looks like this:

$$\text{Net flow} = 25 \text{ gallons/minute} - 30 \text{ gallons/minute} = -5 \text{ gallons/minute.}$$

Notice that the net flow is negative this time. That tells us that the stock of water in the bathtub is losing 5 gallons every minute. Multiplying that by 16 minutes yields 80 gallons again, but this time the tank has lost 80 gallons. It falls from 100 gallons at the beginning of the period down to 20 gallons by the end of the 16-minute period.



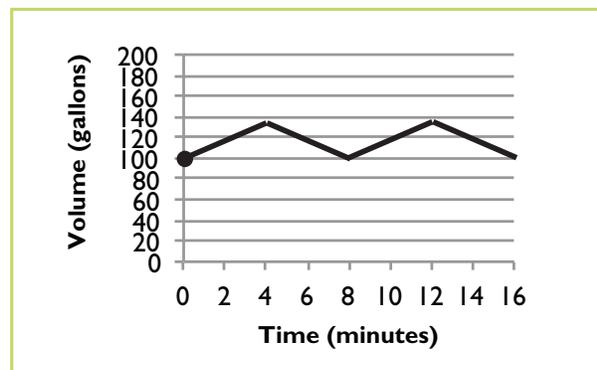
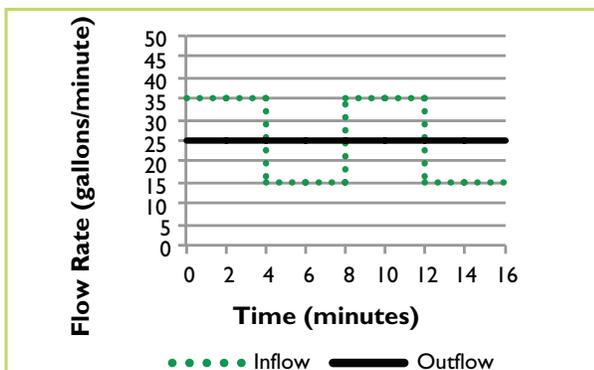
4. This last problem is similar to what the students tried to solve in Booth Sweeney and Sterman's experiment. This time, the outflow stays constant at 25 gallons per minute throughout the entire 16-minute period, but someone is turning the tap every 4 minutes. For just the first 4 minutes, the net flow equation looks like this:

$$\text{Net flow} = 35 \text{ gallons/minute} - 25 \text{ gallons/minute} = 10 \text{ gallons/minute}$$

Multiplying the net flow of 10 gallons per minute by the first 4-minute period tells us that the stock of water increases by 40 gallons during the first 4 minutes (from 100 gallons to 140 gallons). The net flow equation for the next 4 minutes looks like this:

$$\text{Net flow} = 15 \text{ gallons/minute} - 25 \text{ gallons/minute} = -10 \text{ gallons/minute}$$

This time the stock of water is losing 10 gallons per minute, which results in a loss of 40 gallons over the second 4-minute period (from 140 gallons at 4 minutes back down to 100 gallons at 8 minutes). The last 8 minutes simply repeat this pattern, creating the graph below.



**Bathtub Dynamics****Graphing Stocks** (3 of 3)

1. In Graph 1, how much is the volume of water in the tub increasing each minute?

5 gallons/minute

2. In Graph 2, if we decreased the inflow of water by 10%, would we be able to decrease the amount of water in the tub?

No. In Graph 2, the inflow is 30 gallons per minute; 10% of that would be 3 gallons per minute. So, decreasing the inflow by 10% would mean a decrease from 30 gallons/minute to 27 gallons/minute. That makes the new net flow 2 gallons per minute (27 gallons/minute – 25 gallons/minute). Since the net flow is still positive, the volume of water in the tub is still increasing, though at a slower rate than before.

3. In Graph 2, how much would we have to decrease the inflow in order to start reducing the amount of water in the bathtub?

The net flow is currently 5 gallons/minute. Therefore, the inflow must be decreased by more than 5 gallons per minute in order for the net flow to become negative, implying a net decrease in the stock of water. For the net flow to decrease the stock, the outflow must be greater than the inflow.

4. In Graph 2, if we were unable to reduce the inflow by more than 10%, is there any way that we can still decrease the amount of water in the tub?

Yes. The 10% reduction brings the inflow down to 27 gallons per minute, leaving a net flow of 2 gallons per minute. If we increase the outflow to more than 27 gallons per minute, then the net flow will be negative, indicating a decrease in the stock of water.

5. If our bathtub system is a simplified representation of carbon in the atmosphere, list two processes that the faucet flow represents.

The faucet flow represents flow of carbon into the atmosphere, such as from burning fossil fuels or reducing forest cover.

6. What processes does the drain flow represent?

The drain flow represents processes that pull carbon out of the atmosphere, such as reforestation and weathering.

7. Which processes are more important for addressing climate change: inflow processes or outflow processes?

Both. In order to address climate change, we must concentrate on both decreasing carbon emissions into the atmosphere and encourage processes that remove carbon from the atmosphere.