

Roll the Dice: Where Does a Water Molecule Go, and How Long Does It Stay?

Investigation question: If you follow one water molecule through a chance-based model of the water cycle, where does it spend most of its time, which processes move it, and how well does the model match Earth's real reservoirs?

Collaborative systems modeling

Groups of 3

1 session

Setup 8 · Activity 42 · Cleanup 5 min

MS-ESS2-4 · assesses

Name _____

Group _____

Date _____

Your role today

- ☐ **Traveler:** Rolls the die at each station, reads the number aloud, and carries the group's token (or bead string) to the next station.
- ☐ **Recorder:** Writes each move in the journey log: station, roll, where the molecule went or that it stayed, the process named on the station sign, and the driver.
- ☐ **Process checker:** Reads the rule for the roll from the station sign, confirms the process and whether it is Sun-driven, gravity-driven or caused by cooling, and keeps the group's tally sheet.

Safety

- Students move between stations; keep aisles clear, walk, and leave bags under desks.
- Pony beads are a choking hazard for small children; keep them in cups, pick up any that drop, and do not use them in rooms shared with younger students.
- No other hazards; no chemicals, heat or sharp tools are used.

Procedure

1. Before moving, write your prediction in q1: at which station will your molecule spend the most rolls, and which processes will move it most often? Give a reason.
2. Go to your assigned starting station. Record it as move 0 in the journey log and, if using beads, thread one bead of that station's color.
3. On the teacher's signal, the Traveler rolls the die once. The Process checker reads the rule for that number on the station sign and says the process and the driver aloud. The Recorder writes the move: station, roll, 'stayed' or the new station, the process, and the driver (Sun, gravity, cooling, or 'held' for a stay).
4. If the rule says move, walk to the new station and thread a bead of its color; if it says stay, thread another bead of the same color and wait for the next signal. Keep going for 15 moves.
5. After the last move, complete the group tally: for each station, count how many rolls you made there and how many of those were stays. Count the processes by driver.

6. Add your group's numbers to the class tally chart. When all groups are in, compute for each station:
departures = total rolls minus stays, and average stay = total rolls ÷ departures (if a station has zero departures, write 'no departures').
7. Draw your route as a network on the recording sheet: a circle for each station you visited, an arrow for each move, labeled with the process, with loops for stays.
8. Compare the class's average-stay ranking to the approximate real residence-time table, and answer the analysis questions individually.
9. If time allows, each group proposes one rule change for one station that models a real scenario (a warm winter with rain instead of snow, a drought, heavy pumping of groundwater, a paved city) and predicts how the class data would change. Play 8 more moves with the changed rule at that station and check the prediction.

Record your observations

Lab 3 recording sheet: Roll the dice through the water cycle

The station rules below are also posted on the station signs. The die decides every move; your job is to record it accurately, name the process and its driver, and then analyze the class's pooled data.

Station rules (roll a six-sided die)

Station	Rolls 1-2	Rolls 3-4	Roll 5	Roll 6
Ocean	Stay: carried by currents	Stay: carried by currents	Evaporation to Atmosphere (Sun)	Evaporation to Atmosphere (Sun)
Atmosphere	Condensation, then rain to Ocean (cooling, then gravity)	Rain to River (roll 3) or to Soil (roll 4) (cooling, then gravity)	Snow to Snowpack (cooling, then gravity)	Rain to Lake (cooling, then gravity)
Snowpack and glacier	Stay: frozen in place	Stay (roll 3) or melting to River (roll 4) (Sun, then gravity)	Melting, then infiltration to Soil (Sun, then gravity)	Sublimation to Atmosphere (Sun)
River	Stay (roll 1) or flow to Ocean (roll 2) (gravity)	Flow to Ocean (roll 3) or to Lake (roll 4) (gravity)	Evaporation to Atmosphere (Sun)	Seep through the riverbed to Groundwater (gravity)
Lake	Stay: held in the lake	Stay (roll 3) or outflow to River (roll 4) (gravity)	Evaporation to Atmosphere (Sun)	Seep to Groundwater (gravity)
Soil	Stay (roll 1) or evaporation to Atmosphere (roll 2) (Sun)	Root uptake to Plant (Sun, via transpiration pull)	Infiltration to Groundwater (gravity)	Runoff to River (gravity)
Plant	Stay (roll 1) or transpiration to Atmosphere (roll 2) (Sun)	Transpiration to Atmosphere (Sun)	Transpiration to Atmosphere (Sun)	Transpiration to Atmosphere (Sun)
Groundwater	Stay: creeping through pores	Stay: creeping through pores	Spring flow to River (gravity)	Seep out under the sea to Ocean (gravity)

1. Prediction: at which station will your molecule spend the most rolls, and which driver (Sun, gravity or cooling) will move it most often? Explain using the rules.

Journey log

Move	Station	Roll	Stayed, or moved to	Process	Driver (Sun / gravity / cooling / held)
0 (start)					
1					
2					

Move	Station	Roll	Stayed, or moved to	Process	Driver (Sun / gravity / cooling / held)
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

Group tally

Station	Rolls we made here	Of those, stays	Moves driven by the Sun	Moves driven by gravity	Moves that began with cooling
Ocean					
Atmosphere					
Snowpack and glacier					
River					
Lake					
Soil					
Plant					
Groundwater					

Class tally (copy from the board)

Station	Total rolls (all groups)	Stays	Departures (rolls minus stays)	Average stay (rolls ÷ departures)	Rank (1 = longest stay)
Ocean					
Atmosphere					
Snowpack and glacier					
River					
Lake					
Soil					
Plant					
Groundwater					

Approximate real residence times (rough estimates; sources differ)

Reservoir	Typical time water stays
Ocean	thousands of years
Groundwater	years to thousands of years
Glaciers and ice sheets	decades to many thousands of years
Lakes	years to centuries
Seasonal snowpack	months
Soil moisture	weeks to months
Rivers	weeks to months
Plants	days
Atmosphere	about 9 days

-  Draw your route as a network: a circle for each station you visited, one arrow per move labeled with its process, and a loop on a circle for each stay. Mark Sun-driven arrows with a small sun and gravity-driven arrows with a down arrow.



2. After 15 moves: how many different stations did you visit, where was your longest stay and how long was it, and did your prediction in q1 hold? Explain.

Analysis questions

3. Using the class tally, calculate the average stay for the Ocean and for the Atmosphere (average stay = total rolls ÷ departures). Show the numbers. Then explain, using the station rules, why these two values are so different.

4. Compare the class's average-stay ranking with the approximate real residence-time table. Name two reservoirs where the model's ranking agrees with reality and one where it does not, and explain what a single roll stands for in each case.

5. From your group tally, which driver moved your molecule most often: the Sun, gravity or cooling? Explain why every move out of the Atmosphere counts as 'cooling, then gravity' and why no move out of the Ocean counts as gravity.

6. Find a stretch of your route that never touched the Ocean, or one that went up and down between the ground and the air more than once. Describe it, name the processes, and explain why Earth's real water cycle allows that route.

7. Propose one rule change for one station that models a real change: a warm winter with rain instead of snow, a long drought, heavy pumping of groundwater for irrigation, or a city paving over its soil. Write the new rule, say which real process it represents, and predict how the class's average stay at two stations would change.

8. List three things about the real water cycle that this dice model cannot show, and for one of them explain how you would change the model to include it.
