

# Snowpack Down, Creek Up: Two Datasets on Energy and Moving Water

**Learning target:** I can graph and calculate from data to show how a melting snowpack feeds a creek with a delay, and how the rate of evaporation depends on temperature even far below boiling.

Data and graphing   About 45 min   Individual   MS-ESS2-4 · practice   data analysis   independent practice

## Standards connections

**MS-ESS2-4 (practice):** MS-ESS2-4 is a California Grade 6 PE revisited here. Analyzing how snowmelt (sun-driven) becomes streamflow (gravity-driven) with a lag, and how evaporation rate rises with temperature, gives students quantitative reasons for the sun and gravity drivers in the model the PE asks for.

**Purpose:** practice · **Time:** about 45 minutes · **Format:** individual

## Answers with reasoning

### Part A: A snowpack and the creek below it

A snow station on a mountain meadow reports the **snow water equivalent** (SWE) on the first day of each month: the depth of liquid water the snowpack would make if it all melted at once. A gauge on the creek 3 km downhill reports the creek's average flow for the month that follows, in cubic meters per second (m<sup>3</sup>/s). No rain fell between April 15 and September 1.

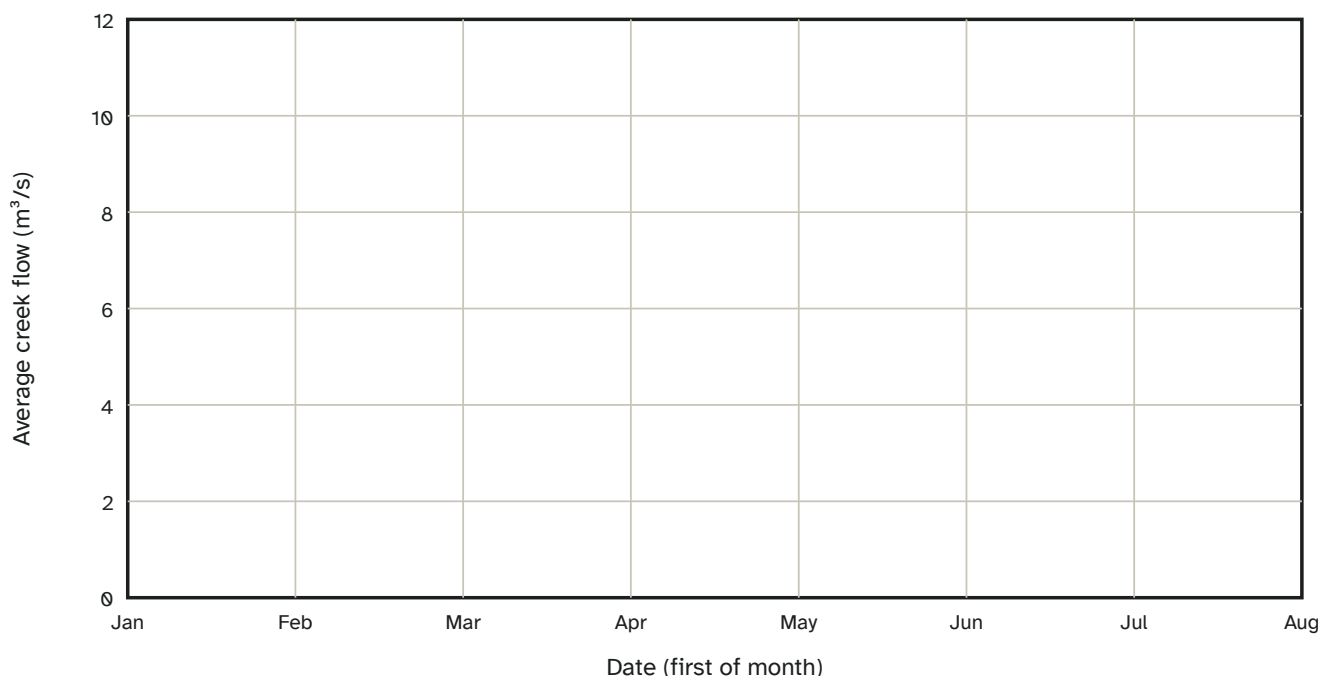
#### Snow water equivalent and creek flow at Granite Meadow (teaching dataset)

*Simulated teaching dataset: the numbers are invented to be realistic, not measured.*

| Date  | SWE on that date (cm) | Average creek flow in the following month (m <sup>3</sup> /s) |
|-------|-----------------------|---------------------------------------------------------------|
| Jan 1 | 40                    | 1.2                                                           |
| Feb 1 | 62                    | 1.4                                                           |
| Mar 1 | 85                    | 2.0                                                           |
| Apr 1 | 98                    | 4.5                                                           |
| May 1 | 70                    | 11.0                                                          |
| Jun 1 | 28                    | 9.5                                                           |
| Jul 1 | 0                     | 3.0                                                           |
| Aug 1 | 0                     | 1.0                                                           |

Simulated data for teaching. The pattern (snow peaking in early April, creek peaking about a month later, creek still flowing after the snow is gone) matches real Sierra Nevada stations.

## Creek flow through the year



1. On which date was the snowpack largest, and what was its SWE? How many centimeters of SWE were lost between that date and July 1? Show the subtraction.

**Answer:** Largest on April 1, SWE 98 cm. Lost by July 1:  $98 \text{ cm} - 0 \text{ cm} = 98 \text{ cm}$ .

**Why:** April 1 is the maximum in the table; by July 1 the snowpack is gone, so the whole 98 cm has left the meadow.

*Also acceptable: None; the date and the subtraction must both appear.*

2. Calculate the average melt rate in cm of SWE per day for April (April 1 to May 1, 30 days) and for May (May 1 to June 1, 31 days). Round to the nearest hundredth. Which month melted faster, and what about the sun explains the difference?

**Answer:** April:  $98 \text{ cm} - 70 \text{ cm} = 28 \text{ cm}$ ;  $28 \text{ cm} \div 30 \text{ days} = 0.93 \text{ cm per day}$ . May:  $70 \text{ cm} - 28 \text{ cm} = 42 \text{ cm}$ ;  $42 \text{ cm} \div 31 \text{ days} = 1.35 \text{ cm per day}$ . May melted faster. In May the sun is higher in the sky and the days are longer, so the snow surface absorbs more energy each day; also, old snow is darker and absorbs sunlight better than fresh snow.

**Why:** The rates are 0.93 and 1.35 cm/day; the explanation should name more solar energy per day (sun angle or day length). The darker-snow point is a bonus.

*Also acceptable: Accept 0.9 and 1.4 cm/day if the student rounded to tenths and said so. Accept 'warmer air' as a partial explanation if it is tied to the sun supplying the energy.*

3. Describe the shape of your creek-flow graph in two sentences: when it rises, when it peaks, and how it falls.

**Answer:** The flow is low and nearly flat from January through March (1.2 to 2.0 m<sup>3</sup>/s), rises in April (4.5) and jumps to its peak in May (11.0). It then falls: still high in June (9.5), down sharply in July (3.0), and back near winter levels by August (1.0).

**Why:** Students should describe rise, peak and fall with the months and at least a few values.

*Also acceptable: Accept 'a mountain shape with the top in May.'*

- Identifies the low winter plateau
- Identifies the May peak
- Describes the decline through August

4. The snowpack peaked on April 1, but the creek's biggest month began on May 1. Explain this one-month delay using at least two processes from the lesson and the two drivers (the sun's energy and gravity).

**Answer:** On April 1 the snow is at its biggest, but it is still a solid sitting on the slope. The sun's energy must first melt it (solid to liquid), which happens faster and faster through April and May. Only then can gravity move the liquid: some runs off over the surface to the creek, and some infiltrates the soil and reaches the creek later as groundwater flow. Melting takes weeks and the trip downhill takes time, so the creek is fullest about a month after the snowpack is largest.

**Why:** Full credit needs melting (sun) before runoff/infiltration/groundwater flow (gravity), plus the idea that both steps take time.

*Also acceptable: A student who says the creek peaks when the melt rate is highest (May, from q2) rather than when the snowpack is biggest has the key insight.*

- Melting named as the sun-driven first step
- Runoff and/or infiltration and groundwater flow named as gravity-driven transport
- Delay explained by melting rate rising through spring and by travel time

5. On July 1 the SWE was 0 cm and no rain had fallen since mid-April, yet the creek averaged 3.0 m<sup>3</sup>/s in July. Where was that water coming from? Name the most likely pathway and explain why it is slow.

**Answer:** From groundwater. Meltwater that infiltrated the soil and rock in April and May is still moving slowly downhill through connected pores under gravity and seeping into the creek bed and springs. It is slow because the water must squeeze through tiny pore spaces instead of flowing freely over the surface. (Snow at higher elevations above the station, still melting, could add some.)

**Why:** Groundwater flow is the expected answer; higher-elevation snow is an acceptable addition but the station's own SWE being 0 points to the stored underground water.

*Also acceptable: Accept 'a lake upstream that is slowly draining' as a second possibility if groundwater is also mentioned.*

- Groundwater flow (or springs fed by infiltrated meltwater)
- Slowness explained by movement through pores

6. Not every centimeter of melted snow reached the creek. Name two pathways by which meltwater could leave the meadow without ever flowing past the creek gauge.

**Answer:** Any two: evaporation from the wet meadow, puddles and the snow surface; sublimation from snow directly to vapor; transpiration by meadow plants and trees that take up meltwater through their roots; infiltration into deep groundwater that flows under the gauge or toward a different valley.

**Why:** Both sun-driven losses (evaporation, sublimation, transpiration) and a gravity-driven bypass (deep groundwater) are valid.

*Also acceptable: Accept 'animals drank it' only alongside a major pathway; it is real but tiny.*

- Two distinct pathways that bypass the gauge

## Part B: How fast does water evaporate?

An evaporation pan is a wide, shallow metal pan of water left outdoors. Each morning a technician measures how much the water level dropped and refills it. No rain fell during these weeks, and the water never got anywhere close to boiling. The table gives the average daily loss for weeks with different average air temperatures.

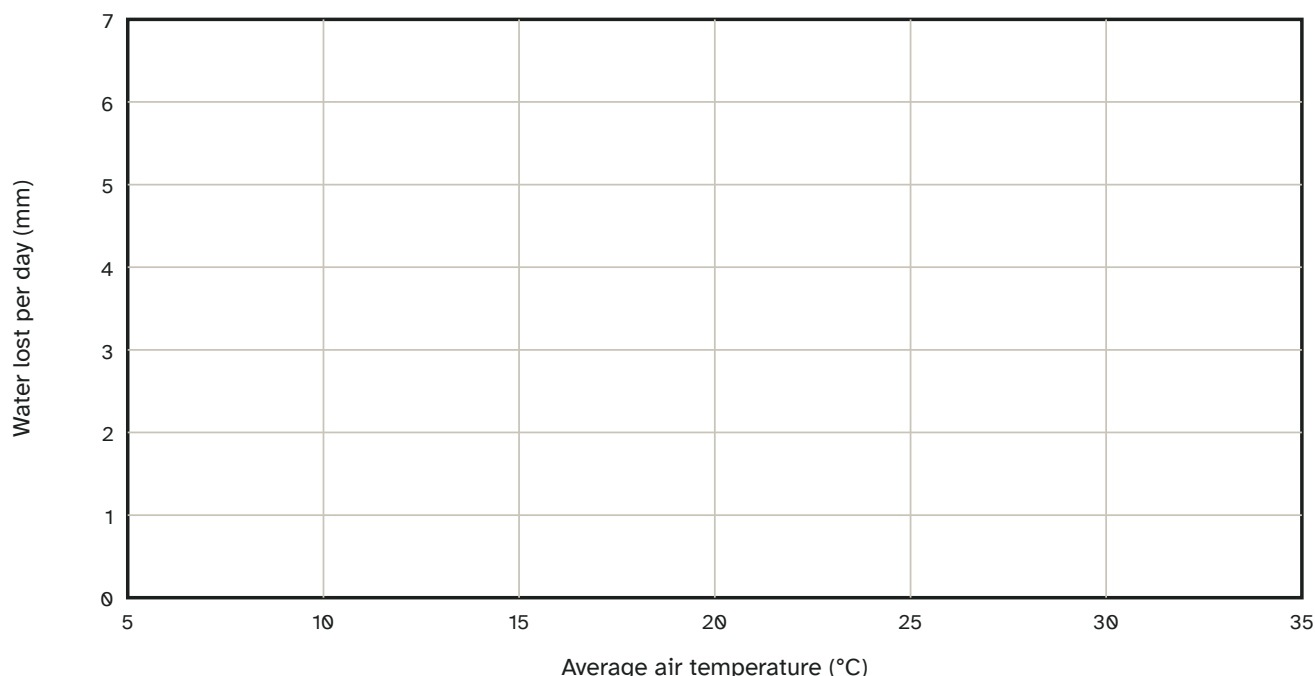
### Evaporation pan losses at different average air temperatures (teaching dataset)

*Simulated teaching dataset: the numbers are invented to be realistic, not measured.*

| Average air temperature (°C) | Average water lost per day (mm) |
|------------------------------|---------------------------------|
| 10                           | 1.5                             |
| 15                           | 2.4                             |
| 20                           | 3.5                             |
| 25                           | 4.9                             |
| 30                           | 6.6                             |

Simulated data for teaching; realistic for a standard pan in calm, dry air. All temperatures are far below the 100 °C boiling point of water.

## Daily evaporation versus air temperature



7. Describe the shape of your Part B graph. Does each extra 5 °C add the **same** amount of evaporation, or more each time? Use two differences from the table as evidence.

**Answer:** The graph curves upward: it gets steeper as temperature rises. Each extra 5 °C adds more evaporation than the last: from 10 to 15 °C the loss rises by 0.9 mm (1.5 to 2.4); from 15 to 20 °C by 1.1 mm; from 20 to 25 °C by 1.4 mm; from 25 to 30 °C by 1.7 mm.

**Why:** Successive differences are 0.9, 1.1, 1.4, 1.7 mm, which grow; the relationship is not linear. Students need two of these differences as evidence.

*Also acceptable: Accept 'the jumps get bigger: 0.9, then 1.1, then 1.4, then 1.7.'*

- Says the curve steepens (not a straight line)
- Cites two differences from the table

8. Suppose a small farm pond has a surface area of 200 m<sup>2</sup> and the average temperature for a 30-day month is 25 °C. Using the table, calculate (a) the depth of water lost in the month in mm and in cm, and (b) the volume lost in liters. (1 mm of depth over 1 m<sup>2</sup> is 1 liter.)

**Answer:** (a) At 25 °C the pan loses 4.9 mm per day; 4.9 mm/day × 30 days = 147 mm = 14.7 cm. (b) 147 mm over 1 m<sup>2</sup> is 147 L, so over 200 m<sup>2</sup>: 147 L × 200 = 29,400 L.

**Why:** Depth times days gives depth lost; depth in mm times area in m<sup>2</sup> gives liters because 1 mm × 1 m<sup>2</sup> = 1 L. The conversion to cm is 147 ÷ 10.

*Also acceptable: Accept 29,400 L or 29.4 m<sup>3</sup> with work shown. A student who writes 147 L per square meter and then multiplies by 200 has done it correctly.*

9. A classmate claims water only evaporates when it boils. Use two rows of the Part B table as evidence against this claim, and explain in terms of water molecules why evaporation can happen at 10 °C.

**Answer:** At 10 °C the pan lost 1.5 mm per day and at 20 °C it lost 3.5 mm per day; both are far below 100 °C, so water clearly evaporates without boiling. It can happen at 10 °C because the molecules in liquid water do not all move at the same speed. Even in cool water, the fastest molecules at the surface have enough energy to break away into the air. Warming the water makes more molecules fast enough, so the rate goes up, but it never has to reach boiling.

**Why:** Evidence: any two rows below 100 °C. Mechanism: a spread of molecular speeds; the fastest surface molecules escape.

*Also acceptable: Accept 'boiling is when the whole liquid turns to gas; evaporation is only the surface.'*

- Two table rows cited as below-boiling evaporation
- Explains that the fastest surface molecules escape, so no boiling is needed

10. Put the two parts together. Part A shows that the sun's energy releases stored snow and gravity carries it downhill. Part B shows that the sun's warmth also sends water back into the air faster as the summer heats up. Using numbers from both datasets, explain why the creek's flow in August (1.0 m<sup>3</sup>/s) is so much lower than in May, even though the valley is warmer in August.

**Answer:** The creek is fed by stored snow, not by warmth itself. In May the snowpack was still releasing water fast (1.35 cm of SWE per day) and gravity carried that melt into the creek (11.0 m<sup>3</sup>/s). By August the snow was gone (SWE 0 since July 1), so there was no new melt to send downhill; the creek had only slow groundwater left, which was draining down (3.0 in July, 1.0 in August). At the same time, the warm summer air pulls water back into the sky faster: at 25 to 30 °C the pan lost 4.9 to 6.6 mm per day, about three to four and a half times the 1.5 mm lost at 10 °C, so evaporation from the meadow, the creek surface and the plants' transpiration took a bigger share of whatever water was left. More warmth with no snow to melt means less water reaching the creek, not more.

**Why:** Full credit uses the SWE-is-zero point, the groundwater decline, and a number from Part B showing higher evaporation in warm months. The central idea is that the sun's energy only helps the creek when there is stored solid water to release.

*Also acceptable: A student who adds that plants transpire more in late summer, further reducing flow, is correct.*

- States that the snow (the source) was gone by August, with a number
- Uses a Part B number to show higher evaporation in warm months
- Connects both to lower August flow

## Teacher notes

Both datasets are simulated but patterned on real Sierra Nevada snow stations and standard evaporation pans; do not present them as measurements. Successive differences in Part B (0.9, 1.1, 1.4, 1.7 mm) were chosen so that the curve clearly bends upward; the real relationship between temperature and the amount of vapor air can hold is also curved. Expect the q2 rates 0.93 and 1.35 cm/day and the q8 result 29,400 L. The extension yields  $0.98 \text{ m} \times 100,000,000 \text{ m}^2 = 98,000,000 \text{ m}^3$  of melt versus roughly  $(4.5 + 11.0 + 9.5) \text{ m}^3/\text{s} \times 2,600,000 \text{ s} = 65,000,000 \text{ m}^3$  past the gauge, so about 66 percent reached the gauge and about a third left by evaporation, sublimation, transpiration or deep groundwater, or was still stored in the soil and groundwater and passed the gauge later in July and August; real basins vary widely around that share. Lesson pages this supports: Heating (printed 234-235 / PDF 270-271) and Gravity (238-239 / 274-275).

### **Scaffold offered to students: Rates are differences divided by time**

A rate tells how much something changes per unit of time. For q2: subtract the later SWE from the earlier SWE to get the change in centimeters, then divide by the number of days between the two dates. Write the subtraction on one line and the division on the next: for example (made-up numbers)  $50\text{ cm} - 20\text{ cm} = 30\text{ cm}$ ;  $30\text{ cm} \div 10\text{ days} = 3.0\text{ cm per day}$ . The unit of your answer is centimeters per day.

### **Extension: Fill the creek with the snow**

Suppose the snow station represents a basin of 100 square kilometers ( $100,000,000\text{ m}^2$ ) that all drains past the creek gauge, and that the whole basin lost the same 98 cm of SWE between April 1 and July 1. Convert that SWE into a volume of water in cubic meters. Then estimate the volume that actually flowed past the gauge in April, May and June using the average flows (multiply each month's  $\text{m}^3/\text{s}$  by the number of seconds in a month, about 2.6 million). Compare the two volumes, calculate what percent of the melt reached the gauge, and explain, with the pathways from q6, where the missing water most likely went.