

Tap Versus Drain: Aquifer Balance and Ore Grade by the Numbers

Learning target: I can graph and calculate from resource data to decide whether a use of a resource is sustainable (no faster than it is replenished), and show how human removal changes where a resource remains.

Data and graphing

About 45 min

Individual

MS-ESS3-1 · practice

MS-ESS3-4 · supports

data analysis

independent practice

Standards connections

MS-ESS3-1 (practice): The PE's clarification stresses that resource distributions are changing because of removal by humans. Computing an aquifer's water balance and the rock moved per tonne of copper gives students quantitative evidence for that change, which they will cite in explanations.

MS-ESS3-4 (supports): Rising pumping and falling ore grade are consumption data of the kind this Grade 8 PE in the California sequence uses; this sheet only touches it as background and does not ask for the population argument.

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

Answers with reasoning

Part A: Is the Red Mesa aquifer being used faster than it refills?

The town of Red Mesa (a made-up town) pumps all of its water from one shallow sand-and-gravel aquifer that rain and snowmelt refill every year. Each year the water agency estimates two numbers: recharge, the volume of rain and snowmelt that soaks down into the aquifer, and pumping, the volume the town's wells remove. It also measures the depth from the ground surface to the top of the groundwater, the water table. The table gives every fourth year.

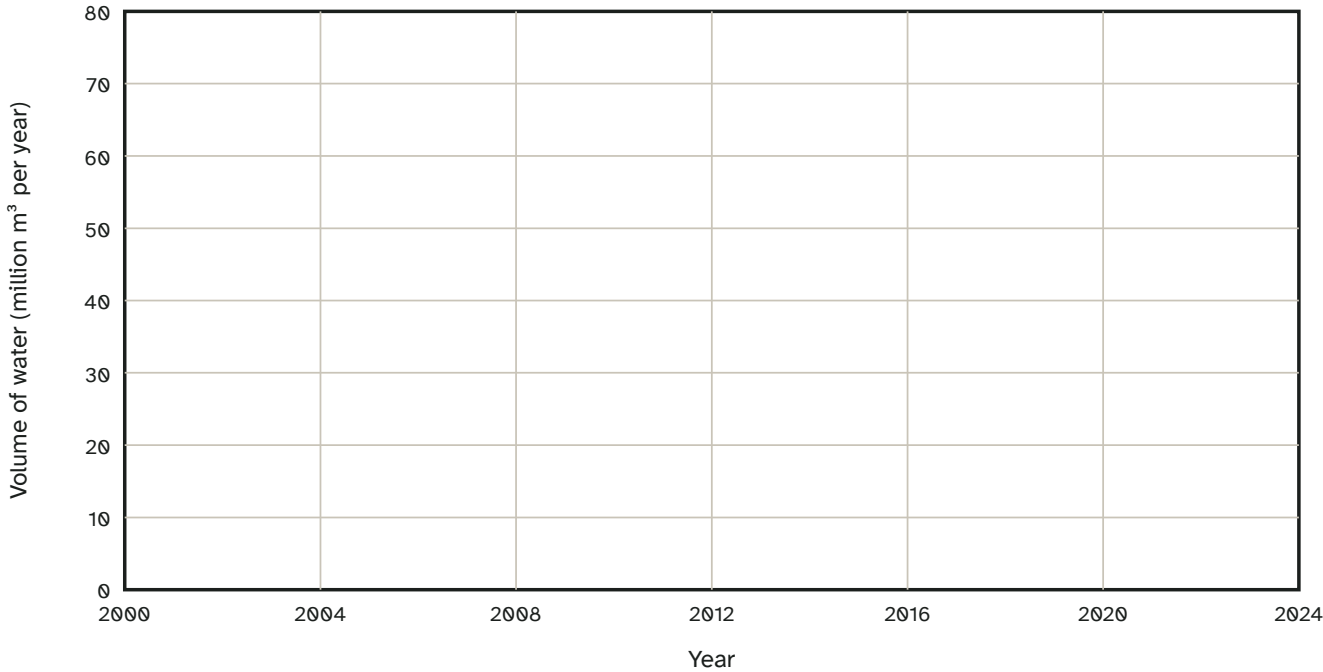
Red Mesa aquifer, 2000-2024 (teaching dataset)

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

Year	Recharge (million m³)	Pumping (million m³)	Depth to water table (m)
2000	42	30	18.0
2004	38	38	18.0
2008	45	46	18.4
2012	31	55	20.1
2016	40	62	22.3
2020	36	70	25.0
2024	39	78	28.4

Simulated data for teaching. Volumes are in millions of cubic meters per year; depth is meters below the ground surface at the agency's monitoring well.

Recharge and pumping at Red Mesa, 2000-2024



1. For each year, subtract pumping from recharge and write whether the aquifer gained water, stayed balanced, or lost water that year.

Answer: 2000: $42 - 30 = +12$, gaining. 2004: $38 - 38 = 0$, balanced. 2008: $45 - 46 = -1$, losing (barely). 2012: $31 - 55 = -24$, losing. 2016: $40 - 62 = -22$, losing. 2020: $36 - 70 = -34$, losing. 2024: $39 - 78 = -39$, losing. (All in million m^3 .)

Why: Simple subtraction; the sign carries the meaning. 2008 is a near-balance that students may call 'balanced'; accept with the -1 shown.

Also acceptable: Accept 'about balanced' for 2008 if the -1 is written.

2. Describe your graph. Which line changes a lot and which stays roughly level? In which year do the lines cross, and what does crossing mean for the aquifer?

Answer: The recharge line stays roughly level, wobbling between about 31 and 45 million m^3 with no trend. The pumping line rises steadily from 30 to 78 million m^3 . The lines cross between 2004 and 2008 (they touch at 38 in 2004 and pumping is above recharge from 2008 on). Crossing means the town began removing more water each year than soaked in, so the aquifer started to lose stored water.

Why: Students should read the crossing as the moment use overtook replenishment.

Also acceptable: Accept 'they meet in 2004 and pumping is above from then on.'

- Recharge described as level, pumping as rising
- Crossing located around 2004-2008
- Crossing interpreted as use exceeding replenishment

3. Calculate the average pumping for 2016, 2020 and 2024 and the average recharge for the same three years. Then calculate how many times larger the pumping is than the recharge. Show your work.

Answer: Average pumping: $(62 + 70 + 78) \div 3 = 210 \div 3 = 70$ million m^3 . Average recharge: $(40 + 36 + 39) \div 3 = 115 \div 3 \approx 38.3$ million m^3 . Ratio: $70 \div 38.3 \approx 1.8$. Pumping is about 1.8 times (nearly twice) the recharge.

Why: Two averages and a ratio. The ratio is the cleanest single statement of the rate comparison that decides whether a use is sustainable.

Also acceptable: Accept 1.83 or 'about 2 times' with the work shown.

4. Look at the depth column. Explain how the depth data support (or do not support) what your net-balance column says is happening. Why does the water table keep dropping even in a year like 2024 when recharge went up?

Answer: The depth data support the net-balance column: in 2000 the net was positive and the water table was shallow (18.0 m), and it held at 18.0 m through the balanced year 2004; once the net turned negative the depth increased every reading, from 18.4 m in 2008 to 28.4 m in 2024, and the biggest drops match the biggest negative balances. The water table still drops in 2024 even though recharge rose from 36 to 39, because pumping (78) is still far larger than recharge (39): the balance is negative (-39), and only the sign of the balance, not the direction of the recharge change, decides whether the aquifer loses water.

Why: This checks that students read two columns against each other and understand that a rising tap still loses when the drain is bigger.

Also acceptable: A student who notes that 2008's tiny loss matches a tiny depth change (18.0 to 18.4) is reading closely.

- States the depth rises when the net balance is negative
- Cites at least one pair of numbers
- Explains 2024 by comparing pumping with recharge, not by the recharge change alone

5. Between 2020 and 2024 the water table dropped from 25.0 m to 28.4 m. Calculate the drop per year. The town's wells reach 40 m. If the drop continues at that rate, in about what year will the water table reach the bottom of the wells? Show your work.

Answer: Drop: $28.4\text{ m} - 25.0\text{ m} = 3.4\text{ m}$ over 4 years. Rate: $3.4\text{ m} \div 4\text{ yr} = 0.85\text{ m per year}$. Remaining depth to the well bottoms: $40\text{ m} - 28.4\text{ m} = 11.6\text{ m}$. Time: $11.6\text{ m} \div 0.85\text{ m/yr} \approx 13.6\text{ years}$. $2024 + 13.6 \approx 2037$ to 2038, so about 2038.

Why: Three-step rate problem. The assumption 'if the drop continues at that rate' is stated in the prompt; in reality the rate would likely worsen as pumping keeps rising.

Also acceptable: Accept 2037 or 2038; accept 14 years. Deduct only for missing units or a missing step.

6. Is Red Mesa's 2024 rate of pumping **sustainable**? Use the numbers to answer. Then state the largest yearly pumping the town could use and still be roughly balanced, and explain how you chose it. Finally, say whether the aquifer's water is still a **renewable** resource, and why that is a separate question.

Answer: Not sustainable. At the 2024 rate the town pumps 78 million m^3 while only 39 million m^3 soaks in, about twice the replenishment, and the water table has dropped more than 10 m since 2000, so the town is using water faster than nature replaces it. The largest roughly balanced pumping is about the average recharge, around 38 to 39 million m^3 per year (the seven-year average is 38.7), because pumping at or below the typical recharge keeps the net balance near zero; a cautious planner would choose a little less, since recharge fell as low as 31 in 2012. The water itself is still renewable: rain and snowmelt refill this shallow aquifer every year, well within a human lifetime. Renewable is about nature's refill time; sustainable is about the town's rate of use, and only the second is failing.

Why: Sustainability comes from the rate comparison; the renewable label comes from nature's refill time, which the Part A text gives (yearly rain and snowmelt into a shallow aquifer). Keeping the two questions apart matches the chapter's definitions and the slide 27 exit ticket. The seven-year recharge average is $(42+38+45+31+40+36+39) \div 7 = 271 \div 7 \approx 38.7$.

Also acceptable: Accept a sustainable rate anywhere from 31 (the minimum recharge) to 39 if the reasoning matches the number chosen. An answer that calls the water nonrenewable 'because it is running out' has merged the two questions: credit the sustainability parts only.

- Answers that the 2024 use is not sustainable, with the pumping-to-recharge comparison
- Names a balanced pumping rate near the average recharge (about 35-40)
- Explains the choice using the recharge values
- States that the water is still renewable because rain and snowmelt refill the aquifer every year, and keeps that separate from the sustainability judgment

Part B: How much rock for a tonne of copper?

Ore grade is the percentage of a rock's mass that is the metal you want. A grade of 1 percent means 1 tonne of copper in every 100 tonnes of ore. Mining companies dug the richest ore first, so the average grade of copper ore mined worldwide has been falling for more than a century. The table describes four imaginary deposits in the same mountain range.

Four copper deposits in the Saddleback Range (teaching dataset)

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

Deposit	Ore grade (% copper)	Ore mined per year (million tonnes)	Year mining began
Ridge	2.0	10	1905
Saddle	1.0	25	1950
Basin	0.5	60	1985
Flat	0.25	80	2015

Simulated data for teaching. Grades of 0.25 to 2 percent span the realistic range for copper mines today.

7. Complete the table. Show one full calculation for each column below the table.

Answer: Ridge: $100 \div 2.0 = 50$ t ore per t copper; $10 \times 2.0 \div 100 = 0.20$ million t copper. Saddle: $100 \div 1.0 = 100$ t; $25 \times 1.0 \div 100 = 0.25$ million t. Basin: $100 \div 0.5 = 200$ t; $60 \times 0.5 \div 100 = 0.30$ million t. Flat: $100 \div 0.25 = 400$ t; $80 \times 0.25 \div 100 = 0.20$ million t.

Why: Both columns are one-step calculations; the second rewards converting a percent to a fraction correctly.

Also acceptable: Accept 200,000 t for 0.20 million t and so on.

8. Which deposit produces the most copper per year, and which one digs up the most rock? Use the numbers to explain why the deposit that produces the most copper is not the one with the richest ore.

Answer: Basin produces the most copper (0.30 million t per year). Flat digs the most rock (80 million t of ore). Basin beats Ridge even though Ridge's ore is four times richer because Basin moves six times as much rock (60 versus 10 million t); the copper produced depends on both the grade and the amount of ore mined, and Basin's larger tonnage more than makes up for its lower grade.

Why: Students must multiply, not just read the grade column.

Also acceptable: Accept 'Basin mines much more ore' as the explanation if a number is cited.

- Basin named for copper, Flat for rock
- Explanation uses both grade and tonnage

9. Look at the 'year mining began' column next to the grade column. Describe the pattern and explain what it tells you about how human choices change which copper is left in Earth's crust.

Answer: The oldest mine (Ridge, 1905) has the richest ore and each newer mine has lower grade, down to Flat at 0.25 percent in 2015. People mined the richest, most accessible ore first; what is left in the crust is lower-grade rock that takes more digging, energy and waste per tonne of copper. Human choices are changing the distribution of copper: the rich deposits are gone from the ground, and the copper that remains is spread thinly through poorer rock, while much of the mined copper now sits above ground in wires and buildings.

Why: This is the 'distributions changing as a result of removal by humans' idea applied to ore grade, and it mirrors the real century-long decline in mined copper grade.

Also acceptable: Accept an answer that focuses on recycling as the consequence if the richest-first pattern is also described.

- Describes the richest-first pattern
- Connects it to what is left in the crust being lower grade
- Mentions more rock, waste or energy per tonne, or copper moving above ground

10. Both parts of this sheet show a resource distribution changing because people remove the resource. Compare the two cases: what is being removed, what (if anything) replaces it, and what single number from each part best shows that the change is happening. Then say which case could be made sustainable by changing the rate of use, and why the other cannot.

Answer: Part A removes groundwater; recharge (about 38 million m³ a year) partly replaces it, but not at the rate of use. Part B removes copper ore; nothing replaces it on a human timescale, since ore takes millions of years to form. Best single numbers: for the aquifer, the pumping-to-recharge ratio of about 1.8 (or the water-table drop of 10.4 m since 2000); for copper, the fall in ore grade from 2.0 to 0.25 percent across the four mines (or 400 t of rock per tonne of copper at Flat versus 50 at Ridge). The aquifer could be made sustainable by cutting pumping to about the recharge, roughly 38 million m³, because the tap is still running; no mining rate can make the copper use sustainable, because nature's tap is effectively off on a human timescale, and no rate of use changes its label: copper ore stays nonrenewable. For copper, the best a community can do is use less, mine carefully and recycle so that copper already mined stays in use; there is no flow to balance.

Why: Full credit requires the comparison in all three parts (what is removed, what replaces it, the key number) and the correct judgment about which case has a replenishing flow to balance.

Also acceptable: A student who argues that recycling and lower demand make copper use closer to sustainable, while noting that the ore is still nonrenewable, is making an accurate distinction; give full credit.

- Identifies what is removed in each case
- States that recharge partly replaces water and nothing replaces ore within human time
- Names one quantitative indicator from each part
- Concludes that only the aquifer can be balanced by changing the rate, with the reason

Teacher notes

Both datasets are simulated. The Red Mesa numbers are scaled like a mid-sized basin and are internally consistent: the water table rises or holds when the net balance is positive or zero and falls faster as the deficit grows. The seven-year average recharge is 38.7 million m³, which is the anchor for q6 and the extension. The copper grades (2.0 to 0.25 percent) match the real spread of modern copper mines, and the richest-first pattern mirrors the real decline in average mined grade over the past century. Common errors: forgetting to divide by 100 in q7's second column, and merging the two questions in q6, either 'nonrenewable because it is running out' or 'sustainable because groundwater is renewable'. The depth column has no simple arithmetic link to the volume columns (that would need the aquifer's area and porosity); if a student asks, say the two are measured separately and should agree in direction, not in size.

Scaffold offered to students: Keep the units on every line

For Part A, write every subtraction as 'recharge – pumping = net', with 'million m³' after each number; a negative net means the aquifer lost water. For the drop-per-year question, first find the total drop (final depth – starting depth), then divide by the number of years between the two readings (4). For Part B, the tonnes-of-ore column is 100 divided by the grade; check it with the 1 percent row, which must come out to 100. The copper column is the ore mined times the grade, divided by 100 to turn the percent into a fraction.

Extension: Finding the sustainable yield

Hydrologists call the pumping rate an aquifer can support over the long run its sustainable yield, and it is usually a little less than the average recharge, because some groundwater must keep flowing out to springs and streams. Using all seven recharge values, compute the average recharge, then propose a sustainable yield that leaves 10 percent of the recharge for springs. Estimate how many years, at the 2024 drop rate, Red Mesa has before it must reach that yield, and write a three-sentence recommendation to the town council that names at least two ways to cut pumping.