

Where Should Pine Ridge Drill? A Geothermal Data Decision

Investigation question: Using temperature-with-depth data from four test holes, which site should a small town choose for a geothermal power plant, and what does each site's data reveal about how energy moves up through the crust?

Data-driven decision

Groups of 4

1 session

Setup 5 · Activity 42 · Cleanup 3 min

MS-ESS2-1 · practice

MS-ESS3-1 · supports

MS-ETS1-2 · practice

Scientific purpose

Students act as the advisory team for a fictional California town choosing a site for a small geothermal plant. They receive a simulated set of borehole temperature profiles from four sites, compute the temperature gradient in degrees per kilometer, extrapolate the depth needed to reach the plant's minimum temperature, cost out drilling and a power line against a budget, and recommend a site in writing. Along the way they discover that a straight-line profile means heat is conducting up through solid rock, while a profile that bends and flattens means hot water is convecting through cracks, which is exactly the kind of site a plant needs.

Why this helps students with this chapter

The chapter says energy flows out of Earth's interior, but students have no evidence for it that they have handled themselves. A table of temperatures that climb with depth at every site is that evidence, and computing a gradient makes the flow measurable. The decision forces students to weigh a hotter-but-costlier site against a cooler-but-wetter one, so the science (conduction versus convection, where the heat is) is what decides the engineering question. It also connects to The Geysers, a real California plant that runs on exactly this kind of hot-rock-plus-water site.

Standards connections

MS-ESS2-1 (practice, energy flowing from Earth's interior toward the surface by conduction and convection): Students read real-looking evidence of energy leaving Earth's interior (rock getting hotter with depth) and distinguish conduction through solid rock from convection of groundwater. This builds the energy-flow half of the PE through data rather than a model.

MS-ESS3-1 (supports, geothermal energy as an unevenly distributed resource): The four sites show that usable geothermal heat is concentrated where past volcanic activity left hot rock near the surface, which previews the resource-distribution explanation developed in Lesson 19.

MS-ETS1-2 (practice, evaluating competing solutions against criteria and constraints): Students compare four candidate sites with a decision matrix built from a temperature criterion, a depth constraint and a budget constraint, and justify a choice. The sites are given, not designed, so the role is practice.

Roles (rotate each session)

- **Data analyst:** Computes the temperature change and gradient for each site and the depth needed to reach 120 °C, and checks the arithmetic with the calculator.
- **Grapher:** Plots all four profiles on one graph in four colors, labels each line, and marks the 120 °C level.
- **Cost accountant:** Fills in the decision matrix: drilling cost, power-line cost, total cost, and whether each site meets every criterion and constraint.
- **Spokesperson:** Leads the group to a decision, drafts the recommendation, and presents it to the class with the strongest objection and the group's reply.

Materials

Item	Quantity	Per	Note
Printed data packet (the recording sheet with the borehole table, site notes and budget)	1	student	
Graph paper or the printed graph grid	1	student	
Calculator	1	group	
Colored pencils, four colors	1 set	group	
Ruler	1	group	
Whiteboard or poster paper for the one-minute presentation	1	group	

Estimated cost: 0 to 3 per class (an estimate; Printing only; calculators, rulers and colored pencils are classroom stock.)

Safety

- No hazards; this is a paper-and-calculator investigation. Remind students that real boreholes and geothermal fluids are dangerous and that the scenario is a model.

Teacher preparation and setup

1. Print one data packet per student and one graph grid per student; print a spare set for the document camera.
2. Work through the arithmetic yourself once so you can spot an unreasonable gradient quickly (anything outside 20 to 110 °C per km means a subtraction or unit error).
3. Decide whether groups present to the whole class or to a paired group; the one-minute pitch with one objection is the fastest format.
4. Have slide 17 (The Geysers) ready to show after the decisions so students can compare their chosen site with a real plant.

Investigation design

Independent variable	The site, which stands for its geologic setting (basin sediment, young volcanic area, hot-spring area, coastal plain)
Dependent variable	Temperature at each depth, the gradient in °C per km, and the depth needed to reach 120 °C
Controlled	The same five depths measured at every site; The same temperature criterion, depth limit and budget applied to every site; The same cost rates for drilling and the power line
Trials	One profile per site in the teaching dataset; students note that a real survey would drill more than one test hole per site and repeat the measurements.
Comparison	Straight-line profiles (Sites A, B, D) against the bending profile (Site C); the hotter deep site (B) against the shallower wet site (C).

Student procedure

1. Read the scenario and the site notes as a group. Underline the one criterion (fluid at 120 °C or hotter), the two constraints (no deeper than 2,500 m; total cost no more than \$5.0 million) and the two cost rates (drilling \$1,000 per meter; power line \$100,000 per kilometer).
2. The grapher plots temperature against depth for all four sites on one grid, one color per site, and draws a horizontal line at 120 °C. Everyone copies the finished graph.
3. The data analyst computes, for each site, the temperature change from 0 m to 2,000 m, then the gradient in °C per km (divide the change by 2 km). Record both in the gradient table.
4. For each site with a straight-line profile, use the gradient to find the depth at which the rock reaches 120 °C: subtract the surface temperature from 120, divide by the gradient, and convert to meters. For Site C, read the depth from the graph instead, because its line bends.
5. The cost accountant computes drilling cost (depth to 120 °C in meters × \$1,000) and power-line cost (distance to town × \$100,000 per km) and adds them. Mark whether each site meets the criterion and both constraints.
6. Discuss the site notes. Which sites already have water in the rock? Which would need water pumped in? Record this in the matrix as a risk.
7. Decide on a site. Write the recommendation in the box: the site, the three numbers that support it (depth, temperature, total cost), and one reason the science of the site makes it reliable.
8. Write the strongest objection a town council member could raise and your group's reply.
9. Present for one minute to another group or the class. Then answer the analysis questions individually.

Expected observations

- Sites A and D plot as nearly straight lines with shallow slopes; Site B is a steep straight line; Site C rises fastest of all to 1,000 m and then almost levels off near 130 °C.
- Gradients: A about 25 °C per km, B about 61.5 °C per km, D about 26.5 °C per km; C about 102 °C per km over the first kilometer and about 13 °C per km over the second.

- Only Sites B and C reach 120 °C within 2,500 m: B at about 1,720 m and C at about 1,125 m (read from the graph between 1,000 and 1,500 m).
- Totals: B about \$1.72 million drilling plus \$3.0 million line, about \$4.72 million, under budget but with high water risk; C about \$1.13 million plus \$1.2 million, about \$2.3 million, with low water risk. A and D fail the depth constraint.

Likely difficulties

- Students divide the temperature change by 2,000 instead of 2 and report a gradient of 0.03; ask what the units are and redirect to °C per km.
- Groups try to compute a single gradient for Site C and get a misleading 57.5 °C per km; insist on reading the 120 °C depth from the graph for C.
- Plotting four lines on one grid gets crowded near the surface; colored pencils and a legend fix it.
- Some groups forget the power line entirely and pick B on drilling cost alone; the matrix columns force the full total.
- Students may treat the 150 °C extrapolation at B as a fact; remind them that beyond 2,000 m the line is a prediction, not data.

Structured debrief

1. Collect each group's choice on the board with its total cost. Most groups land on Site C; some argue for B. Ask the B groups what the water-risk column and the 30 km line did to their total, and ask the C groups what they would do if the plateau at 130 °C turned out to be a thin layer.
2. Put the four gradients side by side: about 25, 61.5, bending, and 26.5 °C per km. Point out that 25 °C per km is close to the average for continental crust, which means even Pine Ridge's quiet valley is leaking interior heat upward by conduction every day.
3. Draw the Site C profile and ask why it bends. Water moving through cracks carries energy by convection and evens out the temperature in the zone it circulates through, so the rock between about 1,000 and 2,000 m sits near one temperature. A straight line means the rock is still and energy crawls through it by conduction.
4. Show slide 17. The Geysers is a Site C type: hot rock left from past volcanic activity, cracked rock, and water that is now partly pumped back in from Santa Rosa because the natural supply was running low. Ask which site note about B predicted that problem.

Recording sheet: what students fill in

Lab 3 recording sheet: Where should Pine Ridge drill?

The scenario (a teaching case; the town and the numbers are invented) — Pine Ridge is a small town in the northern California mountains that wants to build a small geothermal power plant. The plant's turbines need underground fluid at **120 °C or hotter**. The town can afford to drill **no deeper than 2,500 m** and has a **total budget of \$5.0 million** for the well plus the power line to town. Drilling costs **\$1,000 per meter**; the power line costs **\$100,000 per kilometer**. Engineers drilled a 2,000 m test hole at four candidate sites and measured the rock temperature every 500 m.

Borehole temperatures at the four candidate sites (teaching dataset)

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

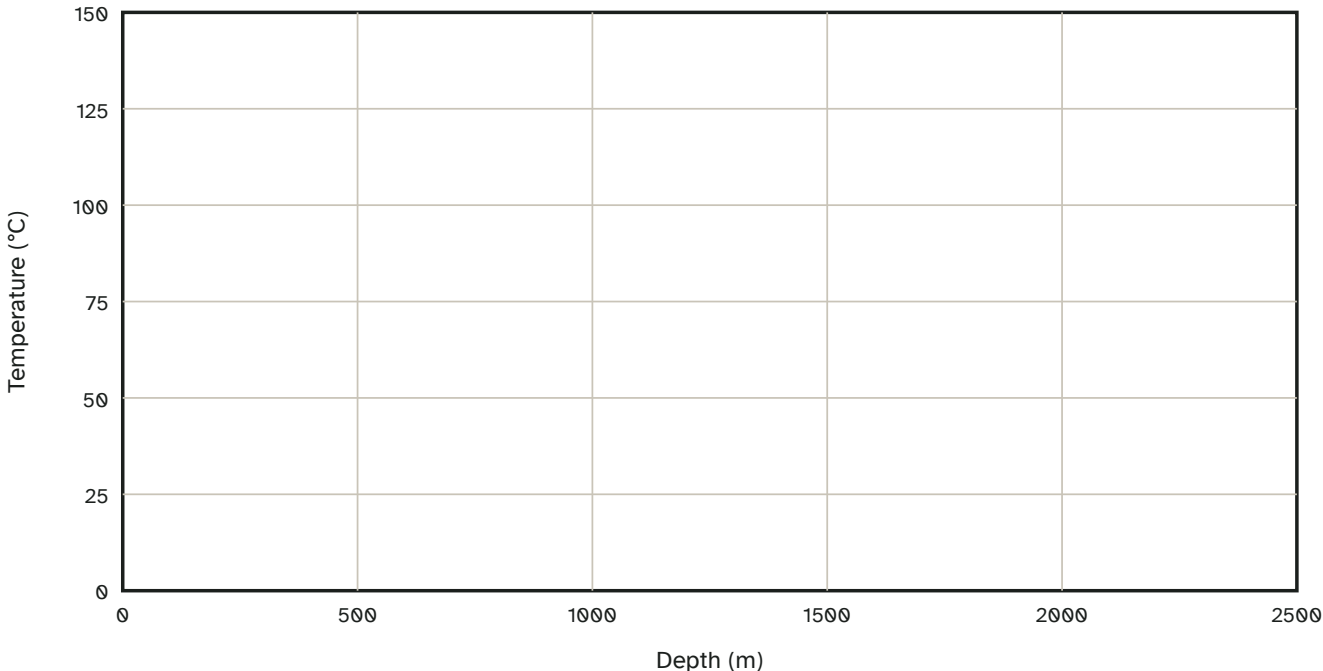
Depth (m)	Site A: valley basin (°C)	Site B: near a young volcanic field (°C)	Site C: hot-spring area, cracked rock (°C)	Site D: coastal plain (°C)
0	15	14	16	17
500	27	45	70	30
1000	40	76	118	44
1500	52	106	126	57
2000	65	137	131	70

Simulated data for teaching. The gradients are realistic for the settings described; the sites are invented.

Site notes from the field team

Site	Distance to town (km)	Water in the rock	Other notes
A	5	Plenty, in a cool shallow aquifer	Flat farmland; easy road access
B	30	Very little; water would have to be pumped in	Lava flows about 10,000 years old nearby
C	12	Plenty; hot springs at the surface bubble at 60 °C	Rock is heavily cracked; steam seen on cold mornings
D	3	Plenty, cool groundwater	Soft sediment; drilling is easy

Temperature versus depth at the four sites



Gradient and depth calculations

Site	Temperature at 0 m (°C)	Temperature at 2,000 m (°C)	Change (°C)	Gradient (°C per km) = change ÷ 2	Depth to reach 120 °C (m)	Is the line straight or does it bend?
A						
B						
C						
D						

Decision matrix

Site	Reaches 120 °C within 2,500 m? (yes/no)	Drilling cost (\$)	Power-line cost (\$)	Total cost (\$)	Under \$5.0 million? (yes/no)	Water risk (low/high)
A						
B						
C						
D						

1. Our recommendation: which site, and the three numbers (depth to 120 °C, temperature available, total cost) that support it. Add one sentence about why the science of this site makes it reliable.

Answer: Site C. Depth to 120 °C about 1,125 m (read from the graph between 1,000 m at 118 °C and 1,500 m at 126 °C); temperature available about 126 to 131 °C; total cost about \$1.13 million drilling plus \$1.2 million power line, about \$2.3 million. The science: hot water is already circulating through cracked rock, which is why the profile flattens, so the plant has both heat and the water needed to carry it.

Why: C is the only site that meets the criterion, both constraints and the low water-risk note. A well-argued B recommendation with the water risk acknowledged and costed as a risk can earn full credit.

Also acceptable: Site B with the correct numbers (about 1,720 m, 120 to 137 °C, about \$4.72 million) and an honest statement that water must be pumped in and the line is long.

- Names a site that meets the criterion and both constraints
- Gives depth, temperature and total cost consistent with the data
- Connects the choice to how energy moves at that site

2. The strongest objection a council member could raise, and your group's reply.

Answer: Example objection: 'Site C's temperature stops rising at about 130 °C, so the plant can never grow; Site B keeps getting hotter.' Reply: the plant only needs 120 °C, C costs less than half as much, and B has no water in the rock, so B would need an extra water supply the budget does not cover; a deeper test hole at C could check whether hotter rock lies below the plateau.

Why: Any objection that uses the data or the site notes, with a reply that uses the criterion, a constraint or the water risk, earns credit.

- Objection is specific to the data or notes
- Reply uses the criterion, a constraint or the water risk

Analysis questions: answer key

3. Compute the gradient for Site A and Site B in °C per km. Show the subtraction and the division. Which site is losing energy from the interior faster, and how do you know?

Answer: Site A: $65 - 15 = 50$ °C over 2 km, so $50 \div 2 = 25$ °C per km. Site B: $137 - 14 = 123$ °C over 2 km, so $123 \div 2 = 61.5$ °C per km. Site B is losing energy from the interior faster: the rock gets hotter more quickly with depth, which means more energy is flowing up through each kilometer of rock.

Why: A steeper gradient means a larger energy flow for the same rock type; students need only the comparison, not the physics of heat flux.

Also acceptable: Accept 61 or 62 °C per km for B with correct working.

4. At Site B, how deep would the town have to drill to reach 120 °C, and how deep to reach 150 °C? Show the calculation for each and give the drilling cost for the 120 °C well.

Answer: 120 °C: $(120 - 14) \div 61.5 = 106 \div 61.5 \approx 1.72$ km $\approx 1,720$ m. 150 °C: $(150 - 14) \div 61.5 = 136 \div 61.5 \approx 2.21$ km $\approx 2,210$ m, which is beyond the 2,000 m of data, so it is a prediction. Drilling cost for the 120 °C well: $1,720 \text{ m} \times \$1,000 = \$1,720,000$ (about \$1.72 million).

Why: Students use the gradient as a rate. Accept answers from 1,700 to 1,750 m and 2,180 to 2,250 m depending on rounding.

Also acceptable: Accept 1,723 m and 2,211 m, or values read from the graph within 50 m of these, with working shown.

5. Site C's line climbs steeply and then flattens, while the other three are nearly straight. Explain what is happening to energy in the rock at each kind of site, using the words conduction and convection.

Answer: At Sites A, B and D the rock is solid and still, so energy from the interior moves up through it by conduction, particle to particle; conduction through uniform rock gives a steady rise in temperature with depth, which is a straight line. At Site C the rock is cracked and full of moving water. Below about 1,000 m hot water circulates through the cracks and carries energy with it by convection, mixing the zone so it all sits near 125 to 130 °C; above that zone the hot water warms the rock from below and energy conducts quickly up through the shallow rock, which is why the first kilometer rises so steeply. The bend marks the top of the convecting water.

Why: This is the lab's main science payoff: the shape of the profile is a fingerprint of the transfer mechanism.

- Straight line linked to conduction through still rock
- Bend and plateau linked to convection of water in cracks
- States that the plateau zone is mixed to a nearly uniform temperature

6. A classmate argues for Site B because it is the hottest at 2,000 m. Using the criterion, both constraints and the site notes, explain whether that argument holds up.

Answer: It only partly holds up. B does meet the criterion (120 °C at about 1,720 m) and the depth constraint, and its total of about \$4.72 million is just under budget. But the site notes say there is very little water in the rock, so the plant would need water pumped in, an extra cost the budget does not include, and the 30 km power line eats most of the budget. Hottest at 2,000 m is not the criterion; the criterion is 120 °C, which C reaches shallower and cheaper with water already there. B is a possible choice only if the town can pay for a water supply.

Why: Students must separate 'hottest' from 'meets the criteria within the constraints.'

- Checks B against the criterion and both constraints with numbers
- Uses the water-risk note
- Concludes with a judgment that compares B with C

7. Every site gets warmer with depth, even the ones far from any volcano. Where is that energy coming from, and how is it reaching the surface at Site A?

Answer: From Earth's hot interior: the core and the mantle are far hotter than the surface, so energy flows outward everywhere, not only near volcanoes. At Site A it reaches the surface by conduction through the solid crust, which is why the temperature rises steadily, about 25 °C for every kilometer down.

Why: Reinforces that interior heat is global; volcanic areas are simply where it is concentrated and shallow.

- Names the interior as the source
- Names conduction through solid rock at Site A

8. Before the town spends \$5 million, what one extra measurement or test hole would you ask the engineers for, and what result would change your recommendation?

Answer: Examples: a second, deeper test hole at Site C to see whether the plateau continues or hotter rock lies below (if the temperature dropped below 120 °C deeper down, the hot zone might be thin and the recommendation would change); a flow test at C to measure how much hot water the cracks deliver (too little flow would push the choice toward B); a water-supply cost estimate for B (a cheap supply could make B competitive).

Why: Any proposed test tied to a stated result that would change the decision earns credit; this is the iterative-testing habit from the Biosphere 2 strand.

- Names a specific measurement or test hole
- States the result that would change the recommendation

Individual evidence of learning

Each student submits the completed graph, the gradient table, the decision matrix, the recommendation and objection boxes, and answers to q3 through q8. The gradient calculations and q5 are the evidence for the energy-flow target; q6 and the matrix are the evidence for evaluating a decision against criteria and constraints.

Assessment criteria

Criterion	Proficient looks like
Graph and calculations	All four profiles plotted and labeled correctly; gradients computed in °C per km with working shown; depth to 120 °C found by calculation for straight lines and by reading the graph for Site C.
Decision against criteria and constraints	Matrix complete and correct; recommendation names a site that meets the temperature criterion and both constraints and cites the supporting numbers; the objection and reply are specific.
Energy-transfer reasoning	Explains straight profiles as conduction through still rock and the bending profile as convection of groundwater, and identifies Earth's interior as the energy source at every site.
Judgment about evidence	Treats extrapolation beyond 2,000 m as a prediction, recognizes the water-risk note as part of the decision, and proposes a sensible further test.

Accessibility adaptations

- Provide a version of the data packet with Site A already plotted and its gradient computed as a worked example.
- Offer a large-print grid with the 120 °C line pre-drawn and 2 cm rows in the tables for students with low vision or limited fine-motor control.
- Let multilingual learners build the recommendation from a sentence frame ('We recommend Site ___ because at ___ m the rock reaches ___ °C and the total cost is ___') and present with the graph rather than a written paragraph.
- Allow the analysis questions to be answered as a recorded explanation while pointing at the graph.

Low-cost alternative

Project the data table and have groups work on whiteboards instead of printed packets; one shared graph on the board with four students plotting one site each works for a class short on paper.

Model limitations

The dataset is invented, with gradients chosen to be realistic for each setting (about 25 °C per km is typical continental crust; 60 °C per km and more occurs near young volcanic rock; hot-spring sites often show a convective plateau). Real boreholes give noisier data, real decisions involve permits, land, water rights, plant type and many more costs than two, and 120 °C is a simplified threshold for a small binary-cycle plant. A real survey would also drill several holes per site. This activity has not been physically tested with students; the 42-minute pacing is an estimate.

Teacher notes

Keep the 2,500 m constraint visible; it eliminates A (120 °C would need about 4,200 m) and D (about 3,900 m) cleanly, so the real debate is B versus C. If a group computes a single gradient for C (57.5 °C per km) and uses it to find 120 °C at about 1,800 m, send them back to the graph: the data already pass 120 °C at about 1,125 m. The 150 °C extrapolation at B is a chance to talk about the difference between data and prediction. After the decisions, show The Geysers slide and let students notice that it matches a Site C setting with Site B's water problem solved by piping in treated wastewater.