

Listening to Silver Basin: Design a Volcano Monitoring and Alert Plan

Learning target: I can turn vague goals into precise criteria and constraints, evaluate competing monitoring plans, and design a volcano monitoring network and alert rule that uses precursor data to protect a town.

Transfer and design

About 55 min

Pairs

MS-ESS3-2 · assesses

MS-ETS1-1 · practice

MS-ETS1-2 · practice

engineering design

data analysis

writing

Standards connections

MS-ESS3-2 (assesses, informing the development of technologies to mitigate a hazard's effects): Students use what precursor data reveal about rising magma to design a monitoring technology and an alert rule that would let officials forecast an eruption and act before it. Choosing which signals to measure, and how many must change before raising the alert, is evidence toward the mitigation half of the PE.

MS-ETS1-1 (practice): Students rewrite a county's vague goals as measurable criteria and list the constraints, using the science of precursors (for example, that locating a quake needs at least four stations). The problem frame is supplied, so this practices rather than fully assesses the PE.

MS-ETS1-2 (practice): Students score two competing plans against the same criteria and constraints in a decision table before designing their own. The comparison is systematic but the plans are given, so the sheet practices the PE.

Purpose: extend · **Time:** about 55 minutes · **Format:** pairs

Answers with reasoning

The problem

Silver Basin is a caldera, a huge bowl-shaped hollow about 15 km across that was left behind when a giant eruption emptied the magma chamber beneath it long ago. The ski town of Juniper, home to 2,500 people and up to 10,000 visitors on winter weekends, sits on the south rim. Two years ago, swarms of small earthquakes began, the center of the basin started rising about 2 cm per year, and two hot-spring vents began giving off more carbon dioxide. The volcano observatory has set the alert level at Advisory. The basin has only one old seismometer, in town. The county has \$300,000 to build and run a monitoring network for the next 5 years.

Silver Basin today: background measurements (teaching dataset)

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

Measurement	Current value
Small earthquakes per week	about 10, at 3 to 6 km deep
Uplift at the basin center	about 2 cm per year
Carbon dioxide at each vent	about 50 tonnes per day
Seismometers working	1 (in Juniper)

Simulated data for teaching. These are the current 'normal for now' values that a future change would be compared against.

Map grid of Silver Basin (north at the top)

Row	1	2	3	4	5
A (north rim)	Forest	North rim (no road in winter)	North rim (no road in winter)	Wilderness	Wilderness
B	West rim road	Basin floor	Vent 1 (hot springs)	Basin floor	Wilderness
C	West rim road	Lake	Uplift center	Basin floor	East rim road
D	Basin floor	Lake	Basin floor	Vent 2 (hot springs)	East rim road
E (south rim)	Ranch	Highway	Juniper (old seismometer)	Ski area	Highway

Each cell is about 3 km by 3 km. Rows A to E run north to south; columns 1 to 5 run west to east.

Instrument menu (teaching dataset)

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

Instrument	What it does	Cost to install	Upkeep per year
Seismometer station	Records small earthquakes. Four or more stations around an area are needed to locate quakes and find their depth.	\$20,000	\$2,000
GPS station	Measures ground rising, sinking or shifting to within a few millimeters, all year.	\$15,000	\$1,000
Gas station	Measures carbon dioxide and sulfur dioxide at one vent.	\$35,000	\$5,000
Satellite radar processing	Maps uplift across the whole basin every 12 days, but gives poor results when deep snow covers the ground (December to April).	\$0	\$8,000
Webcam	Shows the vents and steam; cannot see underground.	\$3,000	\$400

Simulated costs for teaching. What each instrument does is accurate; the prices are invented.

The county's goals and rules — The county's goals (too vague): 'The network should catch problems early, cover the volcano well, not cost too much, and help warn the town fast.' **Rules:** No station can be placed in the lake (C2, D2). The wilderness cells (A4, A5, B5) may hold one station in total. Any station on the north rim (A2, A3) needs a solar-and-battery kit costing \$5,000 extra. All instruments send their data by radio to the observatory; that is included in the price.

Part A: Define the problem

1. Calculate the 5-year cost of one of each instrument. Show one calculation below the table. 3 pts

Answer: Seismometer: $\$20,000 + 5 \times \$2,000 = \$30,000$. GPS: $\$15,000 + 5 \times \$1,000 = \$20,000$. Gas: $\$35,000 + 5 \times \$5,000 = \$60,000$. Satellite radar: $\$0 + 5 \times \$8,000 = \$40,000$. Webcam: $\$3,000 + 5 \times \$400 = \$5,000$.

Why: Each total is the install cost plus five years of upkeep. These totals are needed to check every plan against the budget.

Also acceptable: No alternatives; check arithmetic.

2. Rewrite the county's vague goals as **at least four precise criteria** that someone could check with a yes or no (use numbers and grid cells where you can). Then list **at least four constraints**. For each criterion, name the precursor signal it is meant to catch. 5 pts

Answer: Example criteria: (1) At least 4 working seismometers, including the old one, on at least three different sides of the basin, so quakes anywhere beneath it can be located and their depths tracked (catches earthquake swarms and quakes getting shallower). (2) A GPS station at the uplift center (C3) and at least one on the rim as a reference, recording all year (catches swelling ground, including in snow season). (3) A gas station at both vents, B3 and D4 (catches rising carbon dioxide or new sulfur dioxide). (4) Data from every instrument reach the observatory continuously, so a change is seen within a day. Constraints: total 5-year cost of \$300,000 or less; no station in the lake cells C2 and D2; no more than one station in the wilderness cells; north-rim stations need a \$5,000 solar kit; snow makes satellite radar unreliable from December to April.

Why: Precise criteria name quantities, places and signals, and each one is tied to a precursor (earthquakes, uplift, gas). Constraints are the limits from the rules and from the science (snow and radar).

Also acceptable: Accept a criterion for gas at only the vent nearer Juniper (D4) if justified by distance to town, and a criterion about webcam coverage of the vents as a fifth criterion.

- At least four criteria that can be checked yes or no
- Criteria use numbers or grid cells
- Each criterion names the precursor it detects
- At least four constraints, including the budget and the map rules

Part B: Judge two plans

Plan X ('Listen hard'): 8 new seismometers spread around and across the basin (one of them on the north rim at A3), 2 webcams and satellite radar. Total: \$295,000. **Plan Y ('Watch the ground and gas'):** gas stations at both vents, 4 GPS stations, 2 new seismometers at E1 and E5 on the south rim, and satellite radar. Total: \$300,000.

3. Score both plans against your criteria from q2 and the budget.

4 pts

Answer: Seismometers: Plan X yes (9 stations around and across the basin); Plan Y no (only 3, all on the south rim, so quakes cannot be located well and depths are poorly known). Uplift: Plan X partly (satellite radar only, which fails under winter snow); Plan Y yes (4 GPS stations all year, plus radar). Gas: Plan X no (no gas stations); Plan Y yes (both vents). Continuous data: both yes. Budget: Plan X yes (\$295,000); Plan Y yes (\$300,000).

Why: This key uses the example criteria from q2. Students' rows will follow their own criteria; check that each judgment is consistent with the plan as described.

Also acceptable: Credit any well-reasoned scoring that follows the student's own criteria.

- Each plan is scored against each criterion
- Judgments match the plan descriptions
- Plan Y's seismometer weakness and Plan X's missing gas and winter uplift data are identified

4. What is the biggest weakness of each plan? Then explain why a network that measures only one kind of signal is risky. (Hint: a swarm of small earthquakes can grow for weeks and then fade away with no eruption.)

3 pts

Answer: Plan X measures almost only earthquakes; it has no gas data and loses its uplift data under winter snow. Plan Y measures ground and gas well but has only three seismometers, all on one side, so it cannot locate quakes or tell whether they are getting shallower. A one-signal network is risky because a single signal can rise for reasons that have nothing to do with magma reaching the surface, as in a swarm that fades away, and because the most convincing evidence of rising magma is several signals changing together.

Why: Volcano forecasting depends on combining independent signals. Each plan sacrifices one key signal.

Also acceptable: Accept 'false alarms' and 'missed warnings' as the two risks of a one-signal network.

- Names Plan X's missing gas and weak winter uplift data
- Names Plan Y's too few, poorly placed seismometers
- Explains why combining signals matters

Part C: Your design

5. Design your network. List each instrument, where it goes and its 5-year cost (include solar kits). The total must be \$300,000 or less. You do not need to use every row.

4 pts

Answer: Example design: new seismometer at A3 with solar kit (\$30,000 + \$5,000 = \$35,000); new seismometer at B1 (\$30,000); new seismometer at C5 (\$30,000); GPS at C3 (\$20,000); GPS at E1 as rim reference (\$20,000); gas station at B3 (\$60,000); gas station at D4 (\$60,000); satellite radar (\$40,000); webcam at E4 or D3 aimed at Vent 2 (\$5,000). Total: \$35,000 + \$30,000 + \$30,000 + \$20,000 + \$20,000 + \$60,000 + \$60,000 + \$40,000 + \$5,000 = \$300,000.

Why: With the old Juniper station, this gives 4 seismometers on four sides, all-year uplift at the center and rim, and gas at both vents, at exactly the budget. Many other designs are valid.

Also acceptable: Valid designs may use A1 instead of A3 (no solar kit), one wilderness station, or drop the radar and webcam to add a third GPS station. A design that exceeds \$300,000 or places a station in the lake does not meet the constraints.

- Every item placed in an allowed cell
- Solar kit included for any north-rim station
- Correct 5-year costs
- Correct total of \$300,000 or less

6. Explain how your design meets each of your criteria and every rule. Name one trade-off you made (something you wanted but gave up) and why. 4 pts

Answer: Example: 'With the old Juniper seismometer, we have four seismometers on the north (A3), west (B1), east (C5) and south (E3) sides, so quakes under any part of the basin can be located and their depths tracked (criterion 1). GPS at C3 and E1 measure uplift at the center against the rim all year, and the satellite radar maps the whole basin when there is no snow (criterion 2). Gas stations sit on both vents (criterion 3), and all instruments send data by radio (criterion 4). Nothing is in the lake, nothing is in the wilderness, and the A3 station has its solar kit. The total is exactly \$300,000. Trade-off: we wanted a second GPS station on the basin floor, but we kept satellite radar instead because it covers the whole basin for most of the year.'

Why: The explanation must check the design against every criterion and constraint and name a real trade-off.

Also acceptable: Any trade-off that reflects a real choice within the budget earns credit.

- Each criterion is checked against specific items in the design
- Every map rule and the budget are checked
- A trade-off is named with a reason

Part D: The alert rule

Real reference: U.S. Geological Survey volcano alert levels (summarized)

Alert level	What it means
Normal	Typical background, non-eruptive state.
Advisory	Signs of unrest above the known background level.
Watch	Heightened or escalating unrest with increased potential for eruption, timeframe uncertain; or a minor eruption under way.
Warning	A hazardous eruption is imminent, under way or suspected.

Summarized from the USGS Volcano Hazards Program alert-level definitions.

7. Write a rule the observatory could use to raise Silver Basin from **Advisory** to **Watch**. Use numbers from the background table. Explain why your rule needs more than one signal, and how it balances two dangers for Juniper: raising the alert too often (false alarms that empty a ski town) and raising it too late. 5 pts

Answer: Example rule: 'Raise the alert from Advisory to Watch when, for two weeks in a row, at least two of these three are true: (1) more than 30 small earthquakes per week (3 times today's 10), or quakes rising to shallower than 3 km; (2) uplift at the center faster than 4 cm per year (double today's rate); (3) carbon dioxide above 100 tonnes per day at either vent, or any new sulfur dioxide. Requiring two signals guards against a quake swarm or a gas burst that fades on its own, which would empty Juniper for nothing and teach people to ignore alerts. Requiring only two of three, and only two weeks, keeps the rule from waiting so long that 10,000 weekend visitors would have too little time to leave once an eruption became likely.'

Why: This is the forecasting logic of the PE turned into a decision rule. The rule must be quantitative, use multiple signals, and weigh the human costs of false alarms against late warnings.

Also acceptable: Accept other thresholds (for example, 'double' for every signal) and other durations if the reasoning addresses both kinds of error. A rule based on a single signal earns partial credit only if the student explains the trade-off explicitly.

- Rule uses specific numbers tied to the background values
- Rule requires more than one signal (or explains a strong reason for one)
- Explains the false-alarm risk with an impact on Juniper
- Explains the late-warning risk with an impact on Juniper

8. Name one thing your network still cannot do, even if it works perfectly. Then name one mitigation that does not involve instruments that Juniper should add to your plan. 3 pts

Answer: Cannot do: it cannot tell the exact day or size of an eruption, cannot stop an eruption, and may give little warning of a steam-driven blast near a vent. Non-instrument mitigation: marked evacuation routes and a practiced plan for weekend crowds; a hazard map that keeps new buildings out of the most dangerous zones; an alert system that reaches visitors' phones and the ski area; signs closing trails near the vents.

Why: Monitoring supports forecasting, but people still need plans, land-use rules and communication to reduce harm.

Also acceptable: Accept 'it cannot prevent the eruption' as the limitation.

- One real limitation of monitoring
- One non-instrument mitigation step

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
Precise criteria and constraints	Four or more checkable criteria with numbers or grid cells, each tied to a precursor signal; four or more constraints including budget, map rules and the snow limitation.	Four checkable criteria and constraints, but one criterion is vague or not tied to a signal.	Criteria restate the county's goals with few numbers; constraints incomplete.	Criteria and constraints missing or confused with each other.

Evaluation of competing plans	Both plans scored consistently against every criterion and the budget; the key weakness of each is identified and linked to the need for multiple signals.	Both plans scored with one inconsistency; weaknesses identified.	Plans compared in general terms without a criterion-by-criterion check.	No meaningful comparison.
Design and budget	Design meets every criterion and rule, costs are correct, total is within budget, and a real trade-off is explained.	Design meets the rules and budget but misses one criterion, or one cost is wrong.	Design breaks a rule or exceeds the budget, or misses two criteria.	Design incomplete or unrelated to the criteria.
Alert rule and forecasting reasoning	Quantitative multi-signal rule tied to background values; explains both false-alarm and late-warning risks for Juniper; states what the network cannot do.	Multi-signal rule with numbers; addresses one of the two risks well.	Rule is vague or uses a single signal without justification.	No rule, or a rule that names a date for an eruption.

Teacher notes

Silver Basin, Juniper and all prices are invented; the instrument roles are accurate. Real calderas such as Long Valley near Mammoth Lakes are monitored by the USGS California Volcano Observatory with seismometers, GPS, gas measurements and satellite radar, so the design problem is authentic. The 'four or more stations to locate a quake' rule is a simplification: three stations can fix a location on a map in principle, but depth and reliability need more, and real networks use many. Snow does degrade satellite radar results, which is why the menu notes it. The q4 hint about a swarm that fades connects to W6, where the 2009 swarm at Mount Corva faded without an eruption. Expect most pairs to spend too much on seismometers; the decision table in q3 helps them see the missing signals. Mitigation here is community planning and technology, not personal emergency advice.

Scaffold offered to students: Making a criterion precise

A precise criterion can be checked with yes or no. Vague: 'cover the volcano well.' Precise: 'At least 4 working seismometers on at least three different sides of the basin, so a quake anywhere under it can be located.' Ask of each criterion: How many? Where? How often? Which signal? For the budget, add the 5-year cost of each item and any solar kits, and check that the total is \$300,000 or less.

Extension: When the money runs out

In year 3 the county's budget is cut and you must drop \$60,000 of upkeep and equipment from your network. Decide what to remove and explain which precursor you will now detect later or less reliably. Then research how the USGS California Volcano Observatory monitors a real caldera, Long Valley near Mammoth Lakes, and compare its instruments with your design.