

After the Fire: Choosing Debris-Flow Defenses for Sycamore Canyon

Learning target: I can use a debris-flow hazard assessment to evaluate competing defenses against criteria and constraints, combine the best features of several into one plan, and justify the plan with data and its remaining risks.

Transfer and design

About 55 min

Pairs

MS-ESS3-2 · assesses

MS-ETS1-2 · practice

MS-ETS1-3 · practice

engineering design

data analysis

writing

Standards connections

MS-ESS3-2 (assesses, using hazard data to inform the choice of mitigation technologies): Students interpret a post-fire hazard assessment (chance of a debris flow, expected volume and the rainfall burst that would trigger it) and use it to choose and combine structures and a rainfall-based warning. That is the PE's second half, informing the development of technologies to mitigate a hazard. The assessment values are simulated, so the sheet assesses the reasoning rather than conclusions about a real place.

MS-ETS1-2 (practice, evaluating competing solutions with a decision matrix): Pairs eliminate options that break a constraint, then score the rest against four criteria in a matrix. The criteria and scoring scale are supplied, so this practices the systematic evaluation the PE describes rather than assessing it.

MS-ETS1-3 (practice, combining the best characteristics of several solutions): Because no single option meets every criterion, students identify each option's strongest feature and combine several into a plan, as the DART engineers combined three fixes. The options come with engineers' estimates rather than students' own test data, so this is practice.

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

Answers with reasoning

The problem

Last summer a wildfire burned 80 percent of the steep, 6 km² watershed above Sycamore Canyon, a foothill town of 140 homes, an elementary school and a stretch of state highway, all built on the fan of sediment where the canyon opens onto flatter ground. The fire burned away the chaparral whose roots held the soil and left much of the surface water-repellent. An old debris basin at the canyon mouth can hold 20,000 m³ of mud and rock. The rainy season usually begins in about four months.

Post-fire debris-flow hazard assessment for the Sycamore Canyon watershed (teaching dataset)

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

Measure	Estimate
Design storm (rain burst used for planning)	15 minutes of rain falling at 24 mm per hour
Chance of a debris flow if the design storm hits	70 percent
Largest likely debris-flow volume	60,000 m ³
Time from the rain burst to the flow reaching homes	About 10 to 20 minutes
Years of higher danger	Highest in the first one or two rainy seasons, falling as plants regrow

Simulated assessment for teaching, modeled on the kinds of estimates USGS scientists produce for burned watersheds. The design storm is a short, intense burst of rain of the kind that triggered deadly debris flows in Southern California in the past.

Criteria and constraints — Criteria (what success looks like): (1) **Lives**: everyone below the canyon is out of harm's way during a design storm. (2) **Homes**: as many of the 140 homes as possible are protected from a 60,000 m³ flow. (3) **Ready in time**: the defense works before the rainy season. (4) **Upkeep**: the defense can be cleaned out or reset between storms. Constraints (limits that cannot be broken): the total cost must be no more than \$6.0 million, and every part of the plan must be finished within 4 months.

Six options proposed at the county meeting

Options and the county engineer's estimates (teaching dataset)

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

Option	What it is	Cost (\$ million)	Months to finish	Debris held (m ³)	Engineer's notes
A	Enlarge the debris basin to hold 60,000 m ³ in all	5.5	6	40000	Would catch the whole design flow; needs heavy equipment to empty after each flow
B	Four steel ring nets strung across the canyon	2.0	2	20000	Lets water drain through; a flow bigger than the nets can hold spills over; emptied by crane
C	Rain-gauge warning and evacuation plan (six gauges, weather forecasts, phone alerts, door-to-door notice, drills)	0.4	1	none	Can get everyone out if people leave before the burst; protects no buildings; false alarms can wear down trust
D	Deflection walls that steer a flow away from the main neighborhood into the creek channel	2.5	3	none	Protects about 90 of the 140 homes; sends more debris toward the highway crossing; check for damage after storms
E	Mulch and seed the burned slopes from the air	1.0	1	none	Cuts runoff and erosion in light and moderate rain by about 20 percent; little effect in a short, intense burst
F	Buy out and remove 30 homes in the most dangerous zone	18.0	12	none	Removes those households from danger permanently

Simulated estimates for teaching. 'Debris held' is how much of a flow the option can trap; options without a number do not trap debris.

Part A: Use the hazard data

1. If the largest likely flow (60,000 m³) comes down the canyon, how much would the old debris basin fail to hold? What percent of the flow could the old basin hold by itself? Show your work.

Answer: $60,000 \text{ m}^3 - 20,000 \text{ m}^3 = 40,000 \text{ m}^3$ that the old basin could not hold. $20,000 \div 60,000 \times 100 \approx 33$ percent held by the old basin alone.

Why: The old basin holds only a third of the largest likely flow, which is why new defenses are needed.

Also acceptable: Accept 33.3 percent or one third.

2. The assessment says the flow could reach homes about 10 to 20 minutes after the rain burst. Explain what that means for **when** option C's evacuation must happen.

Answer: Ten to twenty minutes is too little time to warn and move 140 households after the rain burst has already started. The evacuation must happen before the burst, as soon as forecasts show that a storm strong enough to produce the design rain is on its way, often hours to a day ahead.

Why: Debris flows follow intense rain within minutes, so warnings tied to forecasts give lead time that warnings tied to observed flows cannot.

Also acceptable: Accept 'the day before the storm' or 'when the weather service forecasts rain that hard.'

- States that 10 to 20 minutes is not enough to evacuate after the burst
- Evacuation must be triggered by the forecast, before the intense rain

3. Which options break a constraint? Name the constraint each one breaks and explain whether it could still be useful in a later year.

Answer: Option A takes 6 months, which breaks the 4-month time limit. Option F costs \$18 million, which breaks the \$6.0 million budget, and takes 12 months, which breaks the time limit. Both could still be useful later: A could be built next summer, while danger is still high in the second rainy season, and F permanently removes the most exposed households if the county finds more money.

Why: Constraints eliminate options for this season, not forever; danger stays high for one or two rainy seasons.

Also acceptable: None.

- A breaks the time constraint
- F breaks the budget (and time) constraint
- Explains a possible later use for at least one

Part B: Evaluate the remaining options

4. Score options B, C, D and E against each criterion: 2 = meets it well, 1 = partly, 0 = not at all. Add the totals. In the margin, write one reason for any score of 0 or 2.

Answer: Example matrix. B: lives 1, homes 1, ready 2, upkeep 1, total 5 (traps 20,000 m³, but a bigger flow spills over; crane cleanout). C: lives 2, homes 0, ready 2, upkeep 2, total 6 (can get everyone out but protects no buildings). D: lives 1, homes 2, ready 1, upkeep 1, total 5 (protects about 90 homes, the most of any option, but takes 3 of the 4 months and pushes debris toward the highway). E: lives 0, homes 0, ready 2, upkeep 2, total 4 (quick and cheap, but little effect in the intense design storm).

Why: Scores are judgments; what matters is that each is justified from the estimates and that no option scores 2 on both lives and homes.

Also acceptable: Accept different scores within one point if justified, for example D 'ready' as 2 because 3 months is within the limit.

- All sixteen cells scored 0 to 2
- Totals added correctly
- Reasons given for the 0s and 2s
- C scores highest on lives and D highest on homes

5. Does any single option meet all four criteria well? Use your matrix to explain what that tells you about how to protect Sycamore Canyon.

Answer: No. The option best at protecting lives (C) protects no homes, the option best at protecting homes (D) does not trap debris or guarantee that people are out of the way, and the nets (B) trap only part of the flow. Because each option is strong on a different criterion, the town needs a combination of several options.

Why: This is the key engineering idea of the lesson's DART story: combining solutions that each address part of the problem.

Also acceptable: None.

- States that no single option meets every criterion
- Cites at least two options and their different strengths
- Concludes that a combination is needed

Part C: Design, justify and test

6. Choose a combination of options that stays within both constraints. Calculate its total cost and how much debris it could hold together with the old basin. Then explain how your plan meets each of the four criteria, using numbers from both datasets.

Answer: Example: B + C + D + E. Cost: $2.0 + 0.4 + 2.5 + 1.0 = \$5.9$ million, under the \$6.0 million limit. Time: every part is finished within 3 months, under the 4-month limit. Debris held: old basin $20,000 \text{ m}^3$ + nets $20,000 \text{ m}^3 = 40,000 \text{ m}^3$ of the $60,000 \text{ m}^3$ design flow. Lives: the warning plan (C) moves everyone out before the design storm arrives. Homes: the nets and basin catch two thirds of the flow, the walls (D) steer much of the remaining $20,000 \text{ m}^3$ away from about 90 homes, and mulching (E) reduces erosion during the smaller storms between big bursts. Ready in time: all parts done before the rainy season. Upkeep: the nets and basin must be emptied after each flow, so the county should reserve money and a crane for cleanout.

Why: Several combinations are valid. B + C + D (\$4.9 million) is also strong; C + D + E (\$3.9 million) protects lives but traps no new debris. Any plan within both constraints that includes the warning (C) and is justified with numbers can earn full credit.

Also acceptable: Accept plans without C only if the student explains how lives are protected; without a warning plan, the lives criterion is not met, so cap the score.

- Total cost calculated and within \$6.0 million
- All parts finished within 4 months
- Debris held calculated, including the old basin
- Explains how the plan meets each of the four criteria with numbers

7. Pick two options in your plan. For each, name its best characteristic, and explain why the two together meet the criteria better than either one alone.

Answer: Example: The warning plan's best characteristic is that it protects every person for very little money, but it protects no buildings. The ring nets' best characteristic is that they trap 20,000 m³ quickly and let water drain through, but a larger flow can overtop them. Together, the nets and basin cut the flow that reaches town, while the warning means no one is in the way if the nets are overtopped, so lives and homes are both protected better than by either alone.

Why: This is MS-ETS1-3's 'best characteristics of each' combined into a better solution.

Also acceptable: Any pair from the student's plan earns credit if strengths and weaknesses are drawn from the estimates.

- Names a specific strength of each option
- Explains how one covers the other's weakness
- Links the combination to the criteria

8. Write the rule that should trigger option C's evacuation order. Name the data it uses and when the order would go out.

Answer: Example rule: 'When the National Weather Service forecasts a storm that could produce rain at 24 mm per hour or more for 15 minutes over the burn area, order evacuation of the zone below the canyon several hours before the storm arrives, and keep it until the storm passes. If the gauges record rain at that rate without a warning, send an immediate alert.'

Why: The trigger must come from the design-storm threshold in the assessment, and it must act on forecasts because the flow arrives within minutes of the burst.

Also acceptable: Accept a slightly lower threshold for extra safety if the student mentions the trade-off with false alarms.

- Uses the design-storm rainfall intensity
- Uses forecasts (and optionally gauge readings)
- The order goes out before the intense rain

9. What risk remains after your plan is built? Name at least two ways people or property could still be harmed.

Answer: Examples: a flow larger than 60,000 m³ or a second flow before the nets and basin are emptied could overtop them; about 50 homes are outside the walls' protection; debris steered by the walls could damage the highway crossing; people who ignore an evacuation order, or who stop trusting warnings after false alarms, could be caught; a storm stronger than forecast could arrive with little notice.

Why: Mitigation lowers risk but cannot remove it; naming leftover risk is part of an honest design.

Also acceptable: None.

- At least two specific remaining risks
- Each linked to a limit of the plan or the data

10. After the first winter, the county will decide whether to pay for option A next summer. What measurements should crews take after each storm this winter to make that decision, and what result would support building option A?

Answer: After each storm, crews should measure how much debris the nets and the basin trapped, compare it with the rainfall measured by the gauges, and note whether any flow overtopped the nets or reached homes. If storms close to the design storm filled or overtopped the nets and basin, or if the trapped volumes suggest that a design storm would produce more than they can hold, that supports building option A before the second rainy season.

Why: Testing a design and using the results to decide on the next version is the iterative part of engineering.

Also acceptable: Accept measurements of how often the warning was triggered and how many residents evacuated, if linked to the decision.

- Names a measurement of trapped debris or overtopping
- Links it to the rain that caused it
- States the result that would support option A

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
Use of hazard data	Uses the volume, the design storm, the 10 to 20 minute arrival and the danger period correctly to shape the plan, the warning rule and the timing of evacuation.	Uses most of the hazard data correctly; one element, such as evacuation timing, is vague.	Mentions the hazard data but does not use it to make decisions.	Ignores the hazard assessment.
Evaluation against criteria and constraints	Eliminates A and F for the right constraints, completes the matrix with justified scores and correct totals, and concludes that no single option is enough.	Matrix complete and constraints handled, with one unjustified or inconsistent score.	Matrix partly complete, or an eliminated option is treated as allowed.	No systematic comparison.
Combined design	A combination within both constraints, with correct cost and debris totals, that explains how each part covers another's weakness and meets all four criteria.	A valid combination with correct totals, but the explanation of how the parts work together is thin.	A combination that breaks a constraint, or totals that are wrong.	A single option chosen with no combination.
Remaining risk and testing	Names at least two specific remaining risks and a measurement plan that could justify the next design decision.	Names remaining risks and a measurement plan, but one is vague.	Names one risk or one measurement.	Claims the plan makes the town completely safe.

Teacher notes

Sycamore Canyon and all estimates are simulated, but the setting is realistic. USGS post-fire hazard assessments for Southern California have used a design storm of 24 mm per hour sustained for 15 minutes, debris flows commonly follow intense bursts within minutes, the danger is greatest in the first one or two rainy seasons after a fire, and debris basins, ring nets, deflection structures, mulching and forecast-based evacuations are all used in California. In Montecito in January 2018, debris flows from the Thomas Fire burn

area overwhelmed existing basins and killed 23 people; you may share that after students finish q9, as evidence that combined defenses and early evacuation both matter. The best plans include option C, because only a warning protects every life; B + C + D + E (\$5.9 million) and B + C + D (\$4.9 million) are the strongest combinations. Watch for students who add option A's cost as if it were allowed or who forget the old basin's 20,000 m³ in their debris totals.

Scaffold offered to students: Build the plan in layers

Think of protection in three layers and pick at least one option for each. Layer 1, keep people safe: which option gets everyone out before a flow? Layer 2, catch debris: which options trap mud and rock, and how much do they hold together with the old basin's 20,000 m³? Layer 3, steer what gets past: which option keeps the leftover flow away from homes? Add the costs as you go and stop if you pass \$6.0 million.

Extension: Who carries the leftover risk?

Option D protects about 90 homes by steering debris toward the highway crossing and the creek channel. Write a paragraph from the point of view of a family whose home is among the 50 not protected, or of a Caltrans engineer responsible for the highway. Then propose a change to the plan that spreads the remaining risk more fairly, and explain what it would cost in money, time or protection somewhere else.