

Ridgeback Reserve: Design a Drought Plan for a Fenced Elk Herd

Learning target: I can use resource data to find how many elk a fenced reserve can support in wet, average and drought years, identify the limiting resource in each, and design and justify a drought plan that meets criteria and constraints.

Transfer and design

About 50 min

Pairs

MS-LS2-1 · practice

MS-ETS1-2 · practice

engineering design

data analysis

writing

Standards connections

MS-LS2-1 (practice, using resource-supply data to predict population limits in years of abundant and scarce resources): Students calculate the herd each kind of year can support from forage and water supplies, find the limiting resource, and predict what scarcity does to the herd. This applies the PE's cause-and-effect reasoning to a new problem, but the numbers are planning values rather than observed population data, so it is practice rather than assessment.

MS-ETS1-2 (practice, evaluating competing drought plans against criteria and constraints): Pairs evaluate four options and their combinations against stated criteria and constraints with a criteria check table before choosing and defending a plan. This practices the systematic evaluation the PE describes; the options, criteria and check table are supplied, so the sheet builds toward the PE rather than assessing it.

Purpose: extend · **Time:** about 50 minutes · **Format:** pairs

Answers with reasoning

A real case: elk behind a fence

At Point Reyes National Seashore, north of San Francisco, a herd of tule elk at Tomales Point lived behind a fence that kept the elk off neighboring ranch land. In the dry years of 2012 to 2015, the National Park Service's counts of that herd fell from about 540 animals to about 280. Park biologists found no evidence that the elk died of thirst; there was not enough good forage inside the fence for that many elk. (Some groups argued that water ran short too, and the Park Service disagreed.) A free-roaming herd can walk to wherever water and food remain. A fenced herd cannot, so it depends entirely on the resources inside the fence.

The problem: Ridgeback Reserve

Ridgeback Reserve is an imaginary coastal reserve with the same problem. Its 300 elk live inside a fence. Elk need two resources the reserve can run short of: **forage** (grasses and other plants they eat) and **summer water**, because most ponds dry up by the end of a dry summer. The managers expect a drought within the next few years and have asked for a plan. The numbers below are planning values for teaching, not measurements from a real reserve.

Ridgeback Reserve: resources in three kinds of year (teaching dataset)

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

Kind of year	Forage grown (kg per hectare)	Ponds that still hold water at the end of summer
Wet	1800	6
Average	1200	3
Drought	700	1

Simulated planning values. Forage grown is the mass of plants elk can eat that grows on each hectare in a year.

Planning values (teaching dataset)

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

Planning value	Amount
Area inside the fence	1,000 hectares
Forage one elk eats in a year	about 1,500 kg
Share of each year's forage that must be left ungrazed (criterion C4)	one half
Elk that one summer pond can water	about 120
Elk in the herd now	300

Simulated values chosen to be reasonable for tule elk on a coastal grassland.

How to find the carrying capacity — Elk need forage **and** water. First find how many elk the usable forage can feed (forage grown $\times$ area $\times$ one half $\div$ 1,500 kg). Then find how many elk the summer water can supply (ponds $\times$ 120, plus any troughs). The carrying capacity is the **smaller** of the two numbers, and the resource that gives the smaller number is the **limiting resource**. Adding more of the other resource does not help.

Criteria and constraints set by the reserve managers — **Criteria** (what a good plan must do): **C1** In a drought year, the reserve's carrying capacity is at least as large as the herd you plan to keep, so the elk do not die off. **C2** The herd stays at 250 elk or more, the managers' goal for a healthy herd. **C3** The plan keeps working in future droughts without large costs every time. **C4** Elk use no more than half of each year's forage, leaving the rest for soil, other plants and other wildlife. **Constraints** (limits you cannot break): a budget of \$60,000 this year; the main fence stays; no more than 60 elk can be moved this year.

Options and estimated costs (teaching dataset)

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

Option	What it does	Estimated cost	Notes
A. Water trough fed by a solar-powered well pump	Waters about 100 more elk through a dry summer	\$12,000 each, one time	Only 4 sites have groundwater, so at most 4 troughs; each lasts 20 years or more
B. Hay brought in during a drought year	Replaces the forage one elk would otherwise lack that year	\$200 per elk, every drought year	Must be bought again in every drought; elk crowd around feeding sites, where disease spreads more easily
C. Move elk to other public lands	Removes elk from the herd	\$600 per elk	Receiving sites can take at most 60 elk this year; capture is stressful for the animals
D. Open a corridor of neighboring park land	Adds 300 hectares of forage and one pond that holds water even in droughts	\$45,000, one time	Deer and hikers already use the corridor; the half-forage rule applies there too

Simulated cost estimates for teaching. You may combine options and use some of them more than once.

Part A: What can the reserve support with no plan?

1. Complete the table for each kind of year. Show the forage calculation for the drought year below the table.

Answer: Wet: $1,800 \times 1,000 = 1,800,000$ kg grown; half = 900,000 kg usable; $900,000 \div 1,500 = 600$ elk; ponds $6 \times 120 = 720$ elk; carrying capacity 600; limiting resource forage. Average: $1,200,000$ kg grown; 600,000 kg usable; $600,000 \div 1,500 = 400$ elk; ponds $3 \times 120 = 360$ elk; carrying capacity 360; limiting resource water. Drought: $700 \times 1,000 = 700,000$ kg grown; half = 350,000 kg usable; $350,000 \div 1,500 = 233.3$, so 233 elk; ponds $1 \times 120 = 120$ elk; carrying capacity 120; limiting resource water.

Why: The carrying capacity is the smaller of the forage and water numbers. Rounding down 233.3 to 233 follows the direction to round down.

Also acceptable: Accept 233.3 or 234 for the drought forage number if the capacity is still given as 120.

- All usable-forage values correct (900,000; 600,000; 350,000 kg)
- Forage elk 600, 400, 233 and water elk 720, 360, 120
- Capacities 600, 360, 120 with forage, water, water as the limiting resource
- Drought calculation shown

2. The herd is 300 elk now. Predict what will happen to the herd in a drought year if the managers do nothing. About how many elk could be lost, and how does that compare with what happened at Tomales Point?

Answer: In a drought the reserve can support only about 120 elk, because only one pond holds water. With 300 elk, competition for the little water and forage would be severe, and the herd would probably fall toward 120, a loss of about 180 elk, or 60 percent. At Tomales Point the count fell from about 540 to about 280, roughly half, for a similar reason: a fenced herd larger than its dry-year resources could feed (there the short resource was forage).

Why: $300 - 120 = 180$; $180 \div 300 = 60$ percent. The comparison shows the model predicts a crash of the same kind and size as the real case.

Also acceptable: Accept 'more than half the herd' as the size of the loss. A student who notes that the herd would not drop instantly or exactly to 120 is reasoning realistically.

- Predicts the herd falls toward about 120
- Estimates a loss near 180 elk (about 60 percent)
- Compares with the roughly halved Tomales Point herd

3. The limiting resource is not the same in every kind of year. Explain how that can be true, and why it matters when you choose which option to pay for.

Answer: Rain changes both resources, but by different amounts. In a wet year forage is plentiful enough that it runs out first only at 600 elk, while the six ponds could water 720. In average and drought years the ponds dry up faster than the forage shrinks, so water runs short first (360 and 120 elk). It matters because money spent on the resource that is not limiting does nothing: in a drought, adding forage (hay) cannot help while water limits the herd to 120, and adding water helps only until forage becomes the limit.

Why: The limiting resource is whichever is in shortest supply compared with need, and that changes as conditions change.

Also acceptable: Accept a weakest-link analogy if it is tied to the numbers.

- Explains that the two resources respond differently to the kind of year, using the q1 numbers
- Explains that only adding the limiting resource raises the carrying capacity

Part B: Test each option by itself (drought year)

4. For each option used alone, find the drought-year numbers. Start from your drought row in q1 and add only what the option provides.

Answer: 1 trough: \$12,000; forage 233; water $120 + 100 = 220$; capacity 220; lasts, yes. 2 troughs: \$24,000; forage 233; water 320; capacity 233; yes. 4 troughs: \$48,000; forage 233; water 520; capacity 233; yes. Corridor: \$45,000; forage $233 + 70 = 303$ ($300 \times 700 = 210,000$ kg; half = 105,000 kg; $\div 1,500 = 70$); water $120 + 120 = 240$; capacity 240; yes. Hay for 70 elk: $70 \times \$200 = \$14,000$ (again every drought); forage plus hay $233 + 70 = 303$; water 120; capacity 120; no, it must be bought every drought.

Why: Each option is added to the drought baseline (233 forage, 120 water). The key pattern: troughs raise capacity only until forage limits at 233, and hay raises the forage number but not the water number, so it changes nothing while water limits.

Also acceptable: Accept 'partly' for the corridor's 'lasts' column if the student notes that deer also use the corridor.

- All five costs correct
- Corridor forage calculated as 70 extra elk
- Capacities 220, 233, 233, 240, 120
- Lasting judged yes for troughs and corridor, no for hay

5. Your table should show that a third or fourth trough does not raise the drought carrying capacity at all. Explain why, using the term **limiting resource**.

Answer: With two troughs the water supply (320 elk) is already larger than the forage supply (233 elk), so forage has become the limiting resource. A third or fourth trough adds more water, but the herd is now held at 233 by forage, so extra water raises nothing; 4 troughs cost twice as much as 2 for the same capacity of 233.

Why: Adding a resource that is no longer limiting does not raise the carrying capacity; the limit moves to the next scarcest resource.

Also acceptable: Accept an explanation that one trough already brings water to 220, close to forage's 233, so the second trough just passes the forage limit.

- States that forage becomes the limiting resource after two troughs
- Uses the numbers 320 (or more) versus 233

6. Explain why buying hay alone fails criterion C1, and why moving 60 elk alone fails both C1 and C2. Use numbers.

Answer: Hay alone raises the forage number to 303 but leaves the water number at 120, so the drought carrying capacity is still 120, far below a herd of 300 (C1 fails). Moving 60 elk alone shrinks the herd to 240 but leaves the capacity at 120, so 240 is still double what the reserve can support (C1 fails), and 240 is below the goal of 250 (C2 fails).

Why: Hay adds a resource that is not limiting; moving elk lowers the herd without raising the capacity and is capped at 60.

Also acceptable: None needed; the numbers are fixed.

- Hay: water still limits at 120
- Relocation: herd 240 versus capacity 120 (C1) and $240 < 250$ (C2)

Part C: Design, check and defend your plan

7. Write your plan. List each option you chose and how much of it, the total cost this year, the elk the forage (plus any hay) can feed in a drought, the elk the water can supply in a drought, the drought carrying capacity, and the number of elk you plan to keep.

Answer: Two plans meet C1, C2 and the budget. Plan 1 (corridor plus one trough): $\$45,000 + \$12,000 = \$57,000$; drought forage $233 + 70 = 303$ elk; drought water 120 (reserve pond) + 120 (corridor pond) + 100 (trough) = 340 elk; drought carrying capacity 303 ; keep all 300 elk. Plan 2 (two troughs plus drought hay): troughs $\$24,000$; drought water 320 elk; forage 233 , so hay is needed for $300 - 233 = 67$ elk at $\$200 = \$13,400$; total $\$37,400$ in a drought year; capacity 300 ; keep 300 elk. Other combinations can work, for example two troughs, moving 50 elk ($\$30,000$) and hay for 17 elk ($\$3,400$): $\$57,400$, capacity 250 , herd 250 .

Why: Grade the plan on whether the numbers are correct for the options chosen and whether the capacity is at least the herd kept. A plan that fails a criterion can still earn credit for honest checking in q8.

Also acceptable: Plans with three troughs plus hay ($\$36,000 + \$13,400 = \$49,400$) also meet C1 and C2 but waste a trough; accept them with a lower score on justification. Plans that keep fewer than 300 elk by moving some are acceptable if the numbers work and C2 is met.

- Options and amounts listed
- Total cost calculated correctly
- Drought forage and water numbers correct for the chosen options
- Carrying capacity is the smaller of the two
- Herd size kept stated

8. Check your plan against every criterion and constraint. Be honest: 'partly' is an allowed answer if you explain it.

Answer: Plan 1: C1 yes (capacity $303 \geq 300$ elk kept); C2 yes (300 elk); C3 yes (corridor and trough are one-time and keep working); C4 yes (all forage numbers use only half the forage, in the corridor too); budget yes ($\$57,000$); moved elk yes (none). Plan 2: C1 yes ($300 \geq 300$); C2 yes; C3 partly (troughs last, but about $\$13,400$ of hay must be bought every drought and hay piles raise disease risk); C4 yes; budget yes ($\$37,400$ in a drought year); moved elk yes (none).

Why: Every row should be backed by a number or a specific reason. C3 is the criterion that separates the two main plans.

Also acceptable: Accept 'partly' for C4 in Plan 1 if the student argues that deer already eat some corridor forage, so the elk's half may be too generous.

- Every row answered with a number or reason
- C1 judged by comparing capacity with herd kept
- C3 judged honestly (hay is a repeating cost)
- Budget total matches q7

9. Defend your plan in a paragraph. Compare it with at least one other plan that also meets C1 and C2, and explain why yours is better. Name one trade-off your plan accepts, and one way your plan could affect another population that shares the reserve or the corridor.

Answer: Model paragraph (Plan 1): 'We chose the corridor plus one trough. It costs \$57,000, more than the two-troughs-and-hay plan (\$37,400), but it raises the drought carrying capacity to 303 elk permanently, while the hay plan has to buy about \$13,400 of hay in every drought and crowds elk at feeding sites where disease spreads. By the third drought the hay plan would have cost more than ours ($\$24,000 + 3 \times \$13,400 = \$64,200$). Our plan adds water and forage together, so neither one is left as a narrow limit. The trade-off is that we spend almost the whole budget this year and have nothing left for emergencies. The corridor is already used by deer, so elk will compete with them for forage; the half-forage rule leaves food for the deer and other wildlife, but the deer population there could shrink in a drought, so the corridor should be monitored.'

Why: A strong defense compares with a real alternative using numbers, names a cost or risk the plan accepts, and recognizes that adding elk to shared land creates competition with another population.

Also acceptable: A well-argued defense of Plan 2 (cheaper this year, keeps \$22,600 in reserve, troughs last, hay only when needed) earns full credit if it admits the repeating cost and the disease risk.

- Compares with another plan that meets C1 and C2, using numbers
- Explains why the chosen plan is better on at least one criterion (often C3 or cost over time)
- Names one trade-off the plan accepts
- Names an effect on another population (deer, other grazers, plants, insects) and explains it through competition or forage use

10. Suppose your plan works, and then several average years follow. Calculate the average-year carrying capacity with your plan in place. Predict what the herd will do over those years and what will happen at the next drought. What rule or measurement would you add to your plan to prevent that?

Answer: Plan 1, average year: forage on 1,300 hectares = $1,200 \times 1,300 = 1,560,000$ kg; half = 780,000 kg; $\div 1,500 = 520$ elk; water = $3 \text{ ponds} \times 120 + 120$ (corridor pond) + 100 (trough) = 580 elk; capacity 520 (forage limits). Plan 2, average year: forage 400 elk; water $360 + 200 = 560$; capacity 400. In either case the herd will grow above 300 during average years, toward 400 or 520. When the next drought comes, the drought capacity is still only about 300, so the herd would crash again, as the St. Matthew reindeer and the Tomales Point elk did. Rule to add: count the elk and measure forage every year, and keep the herd near the drought carrying capacity (about 300) by moving extra elk in good years, while receiving sites can take them.

Why: A plan sized for one drought fails if the population grows past the drought capacity in good years. The average-year capacity calculation is the evidence that the herd will overshoot.

Also acceptable: Accept any correct average-year capacity for the student's own plan. A rule to buy more hay in later droughts is acceptable if the student recognizes it as a repeating cost.

- Average-year capacity calculated for the student's plan (520 for Plan 1, 400 for Plan 2)
- Predicts the herd grows above the drought capacity
- Predicts a die-off at the next drought
- Adds a monitoring or herd-size rule

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
-----------	---------------	----------------	----------------	---------------

Calculations and limiting resource (q1, q4, q5)	All carrying capacities correct for every kind of year and every option, with the limiting resource named each time and the trough plateau explained with numbers.	One or two numerical slips, but the smaller-of-two rule and the limiting resource are applied correctly.	Several errors, or capacities found from forage alone without comparing water.	Calculations missing or unrelated to the data.
Plan meets criteria and constraints (q7, q8)	The plan's numbers are correct, it meets C1, C2, C4, the budget and the relocation limit, and every row of the check table is backed by a number or a specific reason, including an honest judgment of C3.	The plan meets the main criteria, but one row of the check is unsupported or one number is slightly off.	The plan fails C1 or the budget without the student noticing, or the check table is mostly 'yes' with no evidence.	No workable plan, or no check against the criteria.
Justification and trade-offs (q6, q9)	Compares the plan with a real alternative using numbers, names a trade-off it accepts, and explains an effect on another population through competition for forage or water.	Compares with an alternative and names a trade-off, but the effect on another population is missing or vague.	States a preference without comparing, or lists advantages only.	No justification.
Thinking ahead (q2, q10)	Predicts the no-plan crash with numbers, calculates the average-year capacity for the plan, predicts the herd will outgrow the drought capacity, and adds a specific monitoring or herd-size rule.	Predicts both the crash and the later overshoot, but the rule is vague or one calculation is missing.	Predicts the crash only, or says the plan solves the problem permanently.	No predictions.

Teacher notes

Ridgeback Reserve and every number in its three datasets are simulated planning values; only the Tomales Point case is real. The Tomales Point figures (about 540 elk falling to about 280 between 2012 and 2015 in National Park Service counts; the Park Service blamed too many elk for the poor dry-year forage and found no evidence that elk died of thirst, while some groups argued water was short) match the presentation's California connection slide. Ridgeback's drought water limit belongs to the fictional case, not to Tomales Point. Present it as one fenced herd in a drought, not as a statement about tule elk statewide, whose numbers have grown over the decades. The forage need of about 1,500 kg per elk per year is roughly 4 kg of dry forage a day, a reasonable figure for a tule elk. All key numbers were recomputed: baseline capacities 600, 360 and 120; corridor forage 70 elk; Plan 1 \$57,000 and 303; Plan 2 \$37,400 and 300; average-year capacities 520 and 400. The sheet is designed so that no single option works, more water beyond two troughs is wasted, and hay alone fails because water, not forage, limits the drought herd; these three surprises carry the limiting-resource idea. Expect some pairs to pick Plan 2 because it is cheaper; that is a defensible choice when the repeating cost and disease risk are acknowledged. q10 connects back to the St. Matthew reindeer in W3: a herd that grows in good years overshoots the capacity of a bad year. Extension arithmetic: Plan 1 costs \$57,000 over 20 years; Plan 2 costs \$24,000 + 4 × \$13,400 = \$77,600.

Scaffold offered to students: The calculation in four steps

Step 1: forage grown on the whole reserve = kg per hectare $\times$ 1,000 hectares. Step 2: usable forage = half of that. Step 3: elk the forage can feed = usable forage $\div$ 1,500 kg, rounded down. Step 4: elk the water can supply = ponds $\times$ 120 (add 100 for each trough). The carrying capacity is the smaller of the Step 3 and Step 4 numbers. For the drought year, Step 1 is $700 \times 1,000 = 700,000$ kg. For the corridor, repeat Steps 1-3 with 300 hectares and add the result to the reserve's number.

Extension: The cheapest plan this year, or over twenty years?

Suppose four droughts happen in the next 20 years. Compare the total 20-year cost of a plan built on the corridor and one trough with a plan built on two troughs and drought hay, assuming the herd is 300 at the start of each drought. Then write a paragraph about whether the cheapest plan this year is the cheapest plan overall, and name one cost that is not measured in dollars (for example, the stress of capture or the spread of disease at hay piles).