

Keep the Mussels Out: Designing a Boat Check for a Reservoir

Learning target: I can turn vague goals into precise criteria and constraints, evaluate competing plans for stopping an invasive species with a simple model, and design and justify a better plan within a budget.

Transfer and design

About 55 min

Pairs

MS-LS2-5 · assesses

MS-ETS1-1 · assesses

MS-ETS1-2 · assesses

engineering design

data analysis

writing

Standards connections

MS-LS2-5 (assesses, evaluating competing design solutions for maintaining biodiversity and ecosystem services): Students evaluate two competing prevention plans and design a third for keeping invasive mussels out of a reservoir, judging each on protection of the native food web and water supply (scientific), cost and tourism (economic), and fairness and wait times (social). This is the PE as written, applied to a pressure the lesson treats with a different example (Asian carp).

MS-ETS1-1 (assesses): Part A asks students to turn the board's vague goals into measurable criteria and firm constraints, and Part D asks them to judge whether a criterion is precise enough given how invasions start, which is the precision the PE describes.

MS-ETS1-2 (assesses): Students run each plan through the same calculation and check it against every criterion and the budget before choosing, a systematic evaluation of competing solutions.

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

Answers with reasoning

The situation

Quagga and zebra mussels are small freshwater mussels native to the region around the Black and Caspian Seas. They reached the Great Lakes in the late 1980s, probably in ships' ballast water, were found in Lake Mead, Nevada, in 2007, and have since spread to some California reservoirs, through aqueducts carrying Colorado River water and on trailered boats moved between lakes. Adults can live for days out of water in a damp corner of a boat, and their larvae are too small to see. Once they take hold, they filter huge amounts of plankton out of the water, leaving less food for the small animals and young fish at the base of the food web. They crust over rocks, docks and the shells of native mussels, and they clog the pipes that carry water to treatment plants and power stations. No one has yet found a way to remove them from a large lake.

Sierra Vista Reservoir (invented for this worksheet) stores drinking water for 200,000 people, feeds a small hydropower plant and supports a trout fishery and native fish. It has about 20,000 boat launches each summer and no mussels yet. The district estimates that, with no prevention, about **12 boats carrying live mussels** would arrive each summer.

What the district board said — 'Keep the mussels out.' 'Don't ruin summer for visitors.' 'Know quickly if they get in anyway.' 'Don't make people who did nothing wrong lose their trip.' 'Stay within our money.' The board has \$400,000 a year for prevention and will not allow chemicals in the lake that could harm native fish.

Parts a prevention plan can include (teaching estimates)

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

Part	Cost per summer	Effect in the model	Effect on visitors
A. 'Clean, Drain, Dry' signs and campaign	\$10,000	1 in 4 boats that would have arrived with mussels arrive clean instead	None
B. Inspection station on the entrance road, open 6 a.m. to 8 p.m.	\$220,000	Inspectors find 9 of every 10 boats with mussels that they check and miss 1 in 10	Average weekend wait of 25 minutes
C. Gates that lock the ramps when the station is closed (needs B)	\$40,000	Without gates, 1 in 3 boats with mussels arrives after hours and launches uninspected; with gates, none do	Late arrivals wait until morning
D. Hot-water cleaning unit (needs B)	\$90,000	Boats found with mussels are cleaned and may launch; without D they are turned away	Boats that are cleaned wait about 40 minutes more
E. Monitoring: sampling plates and larva samples every two weeks	\$30,000	Stops no boats, but would find a new mussel population within a year instead of after about three years	None
F. Second inspection crew (needs B)	\$80,000	Same checking as B	Average weekend wait drops from 25 to 10 minutes

Simulated data for teaching. The costs and effects are invented. Hot-water cleaning at about 60 °C is a real method used to kill mussels on boats.

1. Start with 12 boats carrying live mussels in one summer. With part A, multiply by 0.75.
2. Without part B, every one of those boats launches.
3. With B but without C, one third of the arriving boats come after hours and launch uninspected. With C, none do.
4. All other arriving boats are inspected. Missed boats = inspected boats $\times$ 0.1.
5. Contaminated launches = boats that skipped inspection + boats the inspectors missed. Boats that are found are either cleaned (D) or turned away; either way they do not launch with live mussels.

Two competing plans

Plan	Proposed by	Parts
Plan 1	The boaters' club	A + B + F
Plan 2	The water district staff	A + B + C + D + E

Part A: Make the goals precise

1. Rewrite each board statement as a precise criterion (a goal with a number or test) or a constraint (a firm limit). Label which it is.

Answer: 'Keep the mussels out': criterion, for example 'on average fewer than 1 boat with live mussels launches per summer' (or 'no live-mussel launches detected by audits'). 'Don't ruin summer': criterion, for example 'average weekend wait of 20 minutes or less' or 'launches stay at least 18,000 per summer'. 'Know quickly': criterion, for example 'a new population would be detected within one year'. 'Don't make people lose their trip': criterion, for example 'boats found with mussels are cleaned and can still launch the same day'. Budget and chemicals: constraints, 'no more than \$400,000 per summer' and 'no chemical treatments in the lake'.

Why: A precise criterion has a number or a test; a firm limit that rules out designs is a constraint.

Also acceptable: Accept 'Keep the mussels out' as a constraint if written as a firm target with a number.

Accept other reasonable thresholds.

- Every statement given a number or yes-or-no test
- Budget and chemicals identified as constraints
- At least three criteria are measurable

The criteria the board adopted (use these for Parts B and C) — C1 (scientific): on average, fewer than 1 boat with live mussels launches per summer. **C2 (social):** average weekend wait at the entrance of 20 minutes or less. **C3 (scientific):** a monitoring program that would find a new mussel population within one year. **C4 (economic and social):** boats found with mussels are cleaned so visitors can still launch, instead of being turned away. **Constraints:** cost no more than the money available, which is the board's \$400,000 per summer unless a plan raises more (Part C allows one way to do that); no chemicals in the lake.

Part B: Evaluate the competing plans

2. Run both plans through the model. Show the numbers in each box.

Answer: Plan 1: cost \$10,000 + \$220,000 + \$80,000 = \$310,000; arriving $12 \times 0.75 = 9$; skip $9 \div 3 = 3$; inspected $9 - 3 = 6$; missed $6 \times 0.1 = 0.6$; contaminated launches $3 + 0.6 = 3.6$; wait 10 minutes; found boats (5.4) turned away; no monitoring. Plan 2: cost \$10,000 + \$220,000 + \$40,000 + \$90,000 + \$30,000 = \$390,000; arriving 9; skip 0; inspected 9; missed 0.9; contaminated launches 0.9; wait 25 minutes; found boats (8.1) cleaned; monitoring yes.

Why: Each value follows the model's steps in order.

Also acceptable: Accept found boats written as 'about 5' and 'about 8'.

- Costs correct
- Contaminated launches 3.6 and 0.9
- Wait times and the cleaned or turned-away rows correct

3. Check each plan against the criteria and the budget. Write pass or fail and the number or fact that decided it.

Answer: Plan 1: C1 fail (3.6 is not fewer than 1); C2 pass (10 minutes); C3 fail (no monitoring); C4 fail (found boats turned away, no D); budget pass (\$310,000). Plan 2: C1 pass (0.9); C2 fail (25 minutes is more than 20); C3 pass (E included); C4 pass (D included); budget pass (\$390,000).

Why: Neither plan meets every criterion, which is why a third design is needed.

Also acceptable: None.

- All ten cells correct
- The deciding number or fact given

4. Plan 1 includes an inspection station, yet it lets far more mussel boats through than Plan 2. Which missing part causes most of the difference? Use your numbers.

Answer: The gates (part C). Without them, 3 of the 9 arriving mussel boats launch after hours without inspection, which is 3 of Plan 1's 3.6 contaminated launches. Plan 2's gates send all 9 through inspection, leaving only the 0.9 the inspectors miss.

Why: A cheap part that closes a gap can matter more than an expensive part that speeds up the line.

Also acceptable: Accept 'after-hours launches' as the cause if the gates are named as the fix.

- Names the gates
- Uses the numbers 3 (skipped) and 3.6 or 0.9

Part C: Design a better plan

5. Design Plan 3. Choose your parts and run it through the model. You may add **one** way to raise more money (for example, an inspection fee per launch), but you must calculate how much it raises using the 20,000 launches per summer.

Answer: Example 1 (all criteria, with a fee): parts A + B + C + D + E + F cost \$470,000. A \$5 inspection fee × 20,000 launches raises \$100,000, so \$500,000 is available. Contaminated launches 0.9 (C1 pass); wait 10 minutes (C2 pass); found boats cleaned (C4 pass); monitoring (C3 pass). Example 2 (no fee): A + B + C + E + F costs \$380,000; 0.9 contaminated launches; wait 10 minutes; monitoring yes; found boats (about 8 a summer) turned away, so it passes C1, C2 and C3 but fails C4.

Why: Within \$400,000 no package passes all four criteria, so students must either add money or accept a tradeoff. Dropping A is a mistake: without it, even B + C + E + F lets 1.2 boats launch and fails C1.

Also acceptable: Accept any plan run through the model correctly, including ones that keep Plan 2 and add a fee to pay for F.

- Parts chosen and cost totaled correctly
- Model run correctly for the chosen parts
- Any fee calculated from 20,000 launches
- Criteria passed stated accurately

6. Write your recommendation to the board. Explain why Plan 3 is better than Plans 1 and 2, using at least one scientific reason (about the reservoir's food web, native species or water supply), one economic reason and one social reason. Use numbers from the model.

Answer: Example: Plan 3 (A + B + C + D + E + F, paid for with a \$5 launch fee) is the only plan that meets all four criteria. Scientifically, it keeps contaminated launches to 0.9 a summer and adds monitoring, which protects the plankton that young native fish and trout depend on and keeps intake pipes for the drinking water and hydropower plants clear. Economically, it costs \$470,000, which the fee covers, far less than cleaning mussels from pipes every year after an invasion. Socially, the wait falls to 10 minutes and the roughly 8 visitors a summer whose boats carry mussels are cleaned instead of sent home. Plan 1 lets 3.6 mussel boats launch, and Plan 2 makes everyone wait 25 minutes.

Why: The recommendation must compare all three plans and use scientific, economic and social reasons tied to biodiversity and ecosystem services.

Also acceptable: A no-fee plan (A + B + C + E + F) is a strong answer if the student argues that C4 matters less than C1-C3 and explains why.

- Compares Plan 3 with Plans 1 and 2
- A scientific reason tied to the food web, native species or water supply
- An economic and a social reason
- Numbers from the model

7. Name the tradeoff in your plan: which criterion did you meet less well, or who pays more, and why is that acceptable? If you used a fee, explain who pays it and whether it is fair.

Answer: Example with a fee: every boater pays \$5 per launch, including people whose boats were never anywhere near mussels. This is acceptable because everyone benefits from a mussel-free lake, but the district could waive the fee for local residents or low-income families. Example without a fee: about 8 visitors a summer lose their trip because their boats carry mussels; this is acceptable because those boats really were a risk and the lake cannot be cleaned once mussels arrive.

Why: Every design gives something up; a strong answer names who bears the cost and argues about fairness.

Also acceptable: Accept a tradeoff of longer waits if the plan omits F.

- Names a specific tradeoff
- Says who bears the cost
- Gives a reason it is acceptable or proposes a way to soften it

Part D: Test the criteria and plan to monitor

8. Plan 2 lets an average of 0.9 contaminated boats launch per summer. At that rate, about how many contaminated launches would there be over 10 summers? Is C1 precise and strict enough to protect a lake that mussels can never be removed from? Propose a better version of C1.

Answer: $0.9 \times 10 = 9$ contaminated launches in 10 summers. Because a single launch could start a population that can never be removed, C1 is not strict enough. A better version: 'fewer than 1 contaminated launch every 10 summers (0.1 per summer)', or 'no boat with live mussels launches, checked by random audits of 1 in 20 inspected boats'.

Why: A criterion must be precise enough to ensure success given the science of the problem; an average below 1 per summer still adds up to many risky launches over a decade.

Also acceptable: Accept a criterion based on the probability of an invasion in 10 years if it is measurable.

- Calculates 9
- Explains why the criterion is too weak
- Proposes a stricter, measurable criterion

9. Write a monitoring and revision plan for your Plan 3. Name at least three things to measure (at least one about the inspection itself and one about the reservoir), how often, and one result that would make the district change the plan, with the change it would make.

Answer: Example: (1) Audit inspections: each week, a supervisor reinspects a random sample of boats that passed to estimate the miss rate. (2) Sampling plates and larva samples every two weeks at the dam, the marina and the boat ramps. (3) Count weekend wait times and the number of boats arriving after hours at the gates. (4) Check water-intake screens monthly. Trigger: if audits find inspectors missing more than 1 in 10 boats, add training and a second check for boats from states with mussels; if any larvae are found, close the affected ramp, sample the whole reservoir and start a rapid-response plan.

Why: Monitoring must check both whether the plan works as designed (miss rate) and whether the ecosystem is still protected (larvae), with clear triggers for revision.

Also acceptable: Accept counting fee payments or visitor numbers as a social measurement in addition to the two required types.

- At least three measurements, including one about inspections and one about the reservoir
- A schedule
- A trigger and the change it causes

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
Defining criteria and constraints (Parts A and D)	Every goal becomes a measurable criterion or a firm constraint; q8 shows why C1 is too weak and proposes a stricter, measurable version.	Most goals are measurable; q8 calculates 9 and suggests a stricter criterion without full reasoning.	Several goals stay vague, or q8 misses the point that one launch can start an invasion.	Goals copied without being made precise.
Systematic evaluation (Part B)	Both plans run through the model correctly and checked against every criterion and the budget, with the gates identified as the key difference.	One small calculation error; criteria checks consistent with the student's numbers.	Plans only partly run, or criteria checked without numbers.	No systematic comparison.

Design and justification (Part C)	Plan 3 is run correctly, fits the budget (or adds a calculated fee), and is justified against Plans 1 and 2 with scientific, economic and social reasons linked to the food web, native species or water supply; the tradeoff and who bears it are named.	Plan 3 is sound with two kinds of reasons, or the tradeoff is named but not discussed.	Plan 3 has errors or is justified with one kind of reason.	No plan, or a plan that breaks a constraint without a fix.
Monitoring and revision (Part D)	Three or more measurements covering both the inspections and the reservoir, with a schedule, a trigger and a specific change.	Three measurements with a schedule; the trigger or change is vague.	Measurements named without a schedule or trigger.	No plan.

Teacher notes

Sierra Vista Reservoir and every cost and effect are invented and labeled simulated; the model's arithmetic is deliberately simple. The science is real: quagga and zebra mussels are native to the Black and Caspian Sea region, reached the Great Lakes in the late 1980s, were found in Lake Mead in 2007 and have spread to some California reservoirs through Colorado River aqueducts and on trailered boats; they filter out plankton, foul pipes and native mussels, and have not been removed from any large lake. Hot-water decontamination at about 60 °C is standard practice; it needs trained staff because water that hot can scald. Within the \$400,000 budget no plan meets all four criteria, so a full-credit answer either adds a calculated fee or argues for the criterion it gives up. Model results for checking: A+B+F 3.6; A+B+C+D+E 0.9 at 25 minutes; A+B+C+E+F 0.9 at 10 minutes, \$380,000; B+C+E+F 1.2; all six parts \$470,000.

Scaffold offered to students: Work the model one line at a time

Write the five model steps down the side of your page and fill in a number after each one. Example for a plan with only B: start 12; no A, so 12 arrive; no C, so $12 \div 3 = 4$ skip; $12 - 4 = 8$ inspected; $8 \times 0.1 = 0.8$ missed; contaminated launches = $4 + 0.8 = 4.8$. For q1, ask 'How would we know?' and put a number or a yes-or-no test in every answer.

Extension: What the model leaves out

The model treats every inspection as equally good and every summer as the same. List three things in the real world that could make the model wrong (for example, tired inspectors on busy weekends, boats arriving by an unguarded dirt road, or a rise in visitors from a lake that already has mussels). For one of them, change a number in the model, rerun your Plan 3, and explain whether your recommendation still holds.