

Design Challenge: Salt Ponds or Marsh?

Planning a Bay Shoreline

Learning target: I can evaluate competing designs for restoring a bay shoreline against criteria and scientific, economic and social constraints, design an improved plan with calculations, and justify how it maintains biodiversity and ecosystem services.

Transfer and design

About 55 min

Pairs

MS-LS2-5 · assesses

MS-ETS1-2 · practice

MS-ETS1-1 · supports

engineering design

data analysis

writing

Standards connections

MS-LS2-5 (assesses): Students evaluate three competing designs and then their own pond-by-pond plan for maintaining biodiversity (marsh species and waterbirds) and ecosystem services (calmer waves, cleaner water, fish nurseries), judged against scientific, economic and social constraints. This is the PE as written.

MS-ETS1-2 (practice): A pass-or-fail check of every constraint followed by a comparison of criteria is a systematic process for evaluating competing solutions.

MS-ETS1-1 (supports): Part A asks students to sort the problem's requirements into criteria and constraints and to say whether each constraint is scientific, economic or social.

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

Answers with reasoning

Background: a real restoration

For more than a century, companies built shallow ponds along the edge of San Francisco Bay to make salt by letting seawater evaporate. Levees (walls of earth) around the ponds kept the tides out, and the tidal marshes that once grew there disappeared. In 2003, state and federal agencies bought 15,100 acres of these ponds in the South Bay to restore them. The project's goal is to turn at least half of that land back into tidal marsh, which is home to endangered animals such as the California Ridgway's rail and the salt marsh harvest mouse. But the ponds have become important too: tens of thousands of migrating shorebirds and ducks rest and feed in them. So the project opens some ponds to the tides, keeps others as managed ponds, measures what happens, and decides step by step whether to open more.

The problem (simplified for this worksheet) — The Bayview complex has 8 ponds covering 2,000 acres. Today about 30,000 waterbirds use it at the busiest time of year, and it has no tidal marsh. A separate project is already raising the levees behind the ponds, so every design keeps today's flood protection for nearby homes. The team's limits: building can cost no more than \$25 million; yearly upkeep can be no more than \$1.0 million; at least 15,000 waterbirds must still be able to use the complex; and at least half of it, 1,000 acres, must become tidal marsh. Neighbors also want to keep walking the trail on the outer levee. Beyond those limits, the team wants as many marsh animals, as much calming of storm waves near homes, and as fast a marsh as possible.

Three competing designs: predicted results after 20 years (teaching dataset)

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

Measure	A: Open all 8 ponds to the tides	B: Keep all 8 as managed ponds	C: Open about half, keep about half
Tidal marsh (acres)	2,000	0	about 1,000
Ridgway's rail pairs expected	60	0	about 30
Waterbirds at the busiest time (30,000 today)	under 3,000	30,000	about 15,000 to 20,000
Young fish raised in marsh channels	many	none	some
Storm waves calmed before reaching levees	most	little	some
Cost to build (\$ millions)	46	4	about 21 to 25
Yearly upkeep (\$ millions)	0.2	1.6	1.0
Biggest uncertainty	Will enough mud settle to build marsh before sea level rises?	Old pumps and levees wear out and cost more	Which ponds should be opened?

Simulated estimates for teaching, loosely based on the kinds of trade-offs the real South Bay project studies.

The eight Bayview ponds (teaching dataset)

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

Pond	Area (acres)	Mud supply for building marsh	Waterbirds at busiest time	Next to homes?	Cost to open to tides (\$ millions)
P1	300	high	2000	no	6
P2	250	high	6000	no	5
P3	200	low	1500	yes	7
P4	250	medium	5000	yes	6
P5	300	low	8000	no	6
P6	200	high	1000	yes	5
P7	250	medium	3500	no	5
P8	250	low	3000	yes	6

Simulated data for teaching. Rules for this model: an opened pond becomes tidal marsh, and most of its waterbirds leave (count them as lost). Marsh forms in about 10 years where mud supply is high, about 20 where it is medium, and 40 or more where it is low, and low-mud marsh may drown as sea level rises. A marsh next to homes calms waves before they reach the levee. Each pond kept costs \$0.2 million a year to run, and monitoring the new marsh costs \$0.2 million a year.

Part A: Understand the problem

1. Sort each requirement. Write **criterion** (something a design can do better or worse) or **constraint** (a limit every design must meet), and say whether it is mainly scientific, economic or social.

Answer: 1. Constraint, economic. 2. Constraint, scientific (a wildlife requirement set by biologists). 3. Criterion, scientific. 4. Constraint, economic. 5. Constraint, social (an agreed project goal; also scientific because it protects endangered marsh species). 6. Criterion, scientific. 7. Constraint, social. 8. Criterion, scientific (an ecosystem service that also matters socially).

Why: Criteria can be met better or worse; constraints are pass-or-fail limits. MS-LS2-5's clarification names scientific, economic and social constraints.

Also acceptable: Accept 'scientific' or 'social' for item 5, and 'social' for item 8, with a reason.

- Items 1, 2, 4, 5 and 7 identified as constraints
- Items 3, 6 and 8 identified as criteria
- Types are reasonable and justified where two could apply

2. Name three ecosystem services a tidal marsh provides to people in this problem, and one benefit people get from the managed ponds.

Answer: Tidal marsh services: calming storm waves before they reach levees near homes (flood protection), filtering water, raising young fish that people later catch, and storing carbon in marsh mud. Pond benefit: resting and feeding places for migrating waterbirds, which people enjoy watching (recreation), and the trail along the levee.

Why: Ecosystem services are benefits to people; the ponds and the marsh provide different ones.

Also acceptable: Accept birdwatching, education or carbon storage as services.

- Three marsh services
- One pond benefit

Part B: Evaluate the three competing designs

3. Check each design against the four numbered limits from the problem. Write **pass** or **fail** with the number that decides it. In the last row, write whether the design is still in the running.

Answer: Design A: cost 46 > 25, fail; upkeep 0.2, pass; waterbirds under 3,000, fail; marsh 2,000, pass; out. Design B: cost 4, pass; upkeep 1.6 > 1.0, fail; waterbirds 30,000, pass; marsh 0, fail; out. Design C: cost about 21 to 25, pass; upkeep 1.0, pass; waterbirds about 15,000 to 20,000, pass; marsh about 1,000, pass; still in the running.

Why: Constraints are checked first; any failed constraint eliminates a design regardless of its other strengths.

Also acceptable: None.

- A fails cost and waterbirds
- B fails upkeep and marsh
- C passes all four
- Each decision cites the number

4. Even the designs that fail have something valuable. Name the best feature of Design A and of Design B, and explain how Design C borrows from both.

Answer: Design A's best feature: the most tidal marsh, the most Ridgway's rails (60 pairs), the most young fish and wave calming, and almost no upkeep (0.2 million). Design B's best feature: it keeps all 30,000 waterbirds and is cheap to build (\$4 million). Design C borrows marsh habitat and its services from A for half the land and keeps managed ponds for waterbirds from B on the other half, which is why it can meet every limit.

Why: Identifying the best characteristic of each design and combining them is the core engineering move in this chapter.

Also acceptable: None.

- Names a valid best feature of A with a number
- Names a valid best feature of B with a number
- Explains C as a combination of the two

Part C: Build your version of Design C

5. Choose which ponds to open. Fill in your plan's totals. Every limit must be met.

Answer: Model plan: open P1, P4, P6 and P7. Acres: $300 + 250 + 200 + 250 = 1,000$. Cost: $6 + 6 + 5 + 5 = \$22$ million. Waterbirds kept: $30,000 - (2,000 + 5,000 + 1,000 + 3,500) = 30,000 - 11,500 = 18,500$. Upkeep: $4 \text{ ponds kept} \times 0.2 + 0.2 = \$1.0$ million. High or medium mud: all 4 (P1 high, P4 medium, P6 high, P7 medium). Next to homes: 2 (P4, P6).

Why: This plan meets every limit, opens no low-mud ponds (so marsh forms within about 20 years), keeps the two most bird-rich ponds (P5 and P2) and puts marsh in front of two groups of homes.

Also acceptable: Nineteen combinations meet all four limits. Other strong plans: P1, P4, P6, P8 (cost 23, birds kept 19,000, three ponds next to homes, but P8 has low mud); P1, P2, P6, P7 (cost 21, 17,500 birds kept, all high or medium mud, one pond next to homes); P1, P2, P4, P6 (cost 22, 16,000 birds kept, three high-mud ponds). Any plan that meets all four limits with correct arithmetic earns full credit here; the quality of the choice is judged in q7 and q8.

- Plan meets all four limits
- Totals are calculated correctly from the pond table
- At least 4 ponds opened

6. Show the calculations that prove your plan meets all four numbered limits. Explain why your plan must open at least 4 ponds to stay within the upkeep limit.

Answer: For the model plan: build cost $6 + 6 + 5 + 5 = 22$, which is no more than 25. Waterbirds $30,000 - 11,500 = 18,500$, which is at least 15,000. Marsh 1,000 acres, which is at least 1,000. Upkeep $(8 - 4) \times 0.2 + 0.2 = 0.8 + 0.2 = 1.0$, which is no more than 1.0. Opening only 3 ponds would leave 5 ponds to run: $5 \times 0.2 + 0.2 = 1.2$ million, which breaks the upkeep limit, so at least 4 ponds must be opened.

Why: The upkeep rule forces at least four openings; the other limits then decide which four or more.

Also acceptable: Check the student's own plan with the same steps.

- All four limits checked with numbers
- Upkeep calculation shown
- Explains why 3 ponds is not enough (1.2 million)

7. Pond P5 has the most waterbirds but a low mud supply. Pond P6 has few birds, a high mud supply and homes behind it. Explain your decision for each pond, naming the criteria you weighed.

Answer: Model reasoning: Keep P5 as a pond. It holds 8,000 waterbirds, more than a quarter of the total, so opening it would bring the complex close to the 15,000 limit, and its low mud supply means marsh would take 40 years or more and might drown as sea level rises. Open P6. It has only 1,000 birds, a high mud supply so marsh forms in about 10 years, and homes behind it, so the new marsh will calm waves before they reach the levee. The criteria weighed: speed of marsh formation, waterbirds kept and wave protection near homes.

Why: P5 and P6 are designed to be clear choices once mud supply, birds and homes are weighed together.

Also acceptable: A student who opens P5 must show the plan still keeps at least 15,000 birds and acknowledge the slow, risky marsh; full credit only if the trade-off is stated.

- Decision for P5 with reasons from the table
- Decision for P6 with reasons from the table
- Names at least two criteria weighed

Part D: Decide and justify

8. Write a recommendation to the restoration team. Explain why your plan is better than Designs A and B, using at least three numbers. Describe how it maintains biodiversity (name at least two groups of animals) **and** at least two ecosystem services. Say honestly which criterion your plan meets least well and what trade-off you are accepting.

Answer: Model recommendation: We recommend opening P1, P4, P6 and P7 to the tides and keeping P2, P3, P5 and P8 as managed ponds. Design A fails two limits: it costs \$46 million, far over the \$25 million budget, and would leave fewer than 3,000 waterbirds. Design B fails because it costs \$1.6 million a year to run and creates no marsh. Our plan costs \$22 million, keeps 18,500 waterbirds, costs \$1.0 million a year and restores 1,000 acres of marsh. It maintains biodiversity for marsh animals, such as Ridgway's rails, salt marsh harvest mice and young fish in the channels, and for migrating shorebirds and ducks that use the ponds we keep, including the two richest ponds, P5 and P2. It provides ecosystem services: marsh in front of P4 and P6 calms storm waves before they reach the levees near homes, and the marsh filters water and raises young fish. Every pond we open has high or medium mud supply, so marsh should form in 10 to 20 years. The criterion we meet least well is wave protection: only two of the four ponds next to homes become marsh, because P3 and P8 have low mud and P3 is the most expensive to open. We accept that trade-off to get marsh that forms in time.

Why: The justification must compare against the competing designs with numbers, cover both biodiversity and ecosystem services and name a trade-off honestly.

Also acceptable: Any feasible plan earns full credit if the justification meets the criteria.

- Compares the plan with Designs A and B using at least three numbers
- Names at least two groups of animals whose habitat is maintained
- Names at least two ecosystem services
- States the weakest criterion and the trade-off accepted
- Recommendation matches the plan in q5

9. The real project decides step by step. Describe what the team should measure in years 5 to 10 after your plan starts, and what results would tell them to open more ponds or to stop.

Answer: Measure: acres of new marsh plants and how fast mud is building up in each opened pond; the number of Ridgway's rails and harvest mice using the new marsh; peak waterbird counts in the kept ponds; and wave heights at the levees near homes. Open more ponds if marsh is forming on schedule and waterbird counts stay well above 15,000 (for example, above 18,000 for several years). Stop or slow down if waterbird counts fall toward 15,000 or mud is not building up fast enough to keep up with sea level.

Why: This is adaptive management: decisions are tied to measurements and stated thresholds.

Also acceptable: Accept using a diversity index of bird or plant species in each area as one of the measurements.

- At least two things to measure, including one for marsh and one for waterbirds
- A result that would trigger opening more ponds
- A result that would trigger stopping

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
Criteria and constraints	All eight requirements sorted correctly with reasonable types, and the four numbered limits applied as pass-or-fail tests throughout.	Sorting mostly correct (one error); limits applied correctly.	Several sorting errors, or limits treated as preferences rather than tests.	Criteria and constraints confused throughout.
Evaluation of competing designs	Each design checked against every limit with the deciding number; best features of A and B identified and linked to Design C.	Designs checked correctly, but the best features or the link to C are thin.	Some checks missing or wrong, or designs judged by impression.	No systematic evaluation.
Plan and calculations	A plan that meets all four limits with every total calculated correctly, including the upkeep rule, and pond choices explained by mud supply, birds and homes.	Plan meets the limits with one small arithmetic error, or one pond choice is not explained.	Plan breaks one limit, or totals are not shown.	No workable plan.
Justification: biodiversity, ecosystem services and trade-offs	Uses at least three numbers to compare with A and B, names two or more animal groups and two or more ecosystem services, states the weakest criterion and accepted trade-off, and includes a monitoring plan with thresholds.	Covers biodiversity and services with numbers, but the trade-off or the monitoring thresholds are vague.	Describes the plan without comparing designs, or names services without linking them to the plan.	Justification missing or unrelated to the data.

Teacher notes

The background is real: in 2003 state and federal agencies bought 15,100 acres of salt ponds in the South Bay from Cargill, and the South Bay Salt Pond Restoration Project, managed by the California State Coastal Conservancy, the U.S. Fish and Wildlife Service and the California Department of Fish and Wildlife, aims to restore at least half of it (about 7,500 acres) to tidal marsh while keeping enough managed ponds for the waterbirds that use them, adding public access and maintaining flood protection. It uses adaptive management: open ponds in phases, monitor, and expand only if waterbirds are maintained. The California

Ridgway's rail and the salt marsh harvest mouse are federally endangered tidal-marsh species. The Bayview complex, its eight ponds and all numbers are invented. A script checked the pond table: 19 combinations meet all four limits, every feasible plan opens exactly 4 ponds, and the full Design A costs \$46 million (the sum of all eight ponds). The model plan (P1, P4, P6, P7) is one strong answer, not the only one; grade on whether the plan meets the limits and whether the justification weighs the criteria honestly. Common errors: forgetting the \$0.2 million monitoring cost in the upkeep rule, adding the birds of the opened ponds instead of subtracting them, and treating 'at least half marsh' as a preference. This sheet assesses MS-LS2-5 in a bay-shoreline context, different from Lab 3's kelp coast and the presentation's kākāpō habitat task.

Scaffold offered to students: A three-step method for Part C

Step 1: Start with ponds that have a high mud supply, because marsh forms fastest there. Step 2: Add up acres as you go until you reach at least 1,000. Step 3: After each pond you add, subtract its birds from 30,000 and add its cost, and check that you still have at least 15,000 birds and no more than \$25 million. If a limit fails, swap one pond for another with fewer birds or a lower cost. Upkeep: $(8 - \text{ponds opened}) \times 0.2 + 0.2$ must be 1.0 or less.

Extension: Sea level changes the plan

Suppose new measurements show sea level is rising faster than expected, so in this model only marsh with a high mud supply forms in time; medium-mud marsh now takes 40 years. Redo your plan. Can you still meet every limit? If not, which limit would you ask the agencies to change, and why? Write a short paragraph arguing for your choice using numbers from the pond table.