

The Lake Can Give Ten: A Token Model of People, Fish and Fixes

Investigation question: A lake can regrow only so many fish each year. What happens when more and more consumers fish it, when each family starts using more fish, and when a village tries different fixes? And why does a wild fish-eater's population crash while the village's keeps rising?

Collaborative systems modeling

Groups of 4

2 sessions

Setup 5 · Activity 90 · Cleanup 5 min

MS-LS2-5 · practice

MS-ETS1-2 · practice

MS-ESS3-4 · supports

Scientific purpose

Students run a rule-based model of a lake whose fish regrow at a rate that depends on how many are left. They run it first with otters, which can eat only what the lake makes, and then with a fishing village that can import fish when the lake comes up short. The two runs match until the lake runs low; then the otters crash while the village keeps growing and the lake collapses. Next they compare a slowly growing village with one whose fish use per family doubles. In the second session they test five solution cards (a catch limit, larger-mesh nets, a no-fishing reserve, a fish farm and an ice house), alone and in pairs, against three criteria and a budget.

Why this helps students with this chapter

The phenomenon contrasts waves in a wild population with a human line that only rises, and the textbook's investigation asks students to model impacts as populations change at different rates. Moving beans one year at a time makes three ideas concrete: a renewable stock can be harvested for good only below its regrowth rate; a shrinking stock regrows more slowly, so decline speeds up; and the difference between otters and villagers is a single rule, whether food can come from somewhere else. Testing solution cards turns 'engineer it differently' into data, including the sobering result that fixes buy time but cannot keep up forever with a demand that keeps growing.

Standards connections

MS-LS2-5 (practice, comparing competing solutions for keeping a fish population and the lake's food supply healthy): In Part C students test solution cards that stand for real fishery tools and judge them by lake health (a stand-in for biodiversity and the service of a lasting food supply), local supply and cost. The model is supplied and simplified, so this is practice toward evaluating competing design solutions.

MS-ETS1-2 (practice, a systematic check of each design against stated criteria and a budget): Every design posted on the class chart is checked against the same three criteria and the 8-coin budget, so students compare competing solutions with one consistent process. The criteria are supplied, so this is practice.

MS-ESS3-4 (supports, background on population size and use per person): This is a California Grade 8 performance expectation. Part B gives Grade 7 students background for it by comparing growth in the

number of families with growth in fish used per family; the full argument about Earth's systems is left for Grade 8.

Roles (rotate each session)

- **Lake keeper (one in each pair):** Moves the beans: takes out the catch, keeps the last 4 fish on the Reeds card, adds regrowth from the supply bowl, and never lets the lake hold more than 60.
- **Bookkeeper (one in each pair):** Works out each year's fish needed, imports and newcomers from the rule card and fills in the pair's table.
- **Rule checker (one bookkeeper, switching each part):** Reads each step aloud before the lake keeper acts and checks every row: fish at end = fish at start – caught + regrowth, never more than 60.
- **Reporter (one lake keeper):** Posts the group's results on the class charts and reads them aloud during the debrief.

Materials

Item	Quantity	Per	Note
Dried beans (pinto, navy or similar) or paper counters, standing for fish	about 150	group	Enough for two lakes of up to 60 plus a supply bowl.
Clear plastic cups labeled 'Lake'	2	group	
Small cup labeled 'Reserve'	1	group	Used only in Part C.
Bowl labeled 'Supply'	1	group	
Index cards labeled 'Reeds: these 4 fish cannot be caught'	2	group	
Printed rule card, regrowth table and five solution cards	1 set	group	Laminate for reuse.
Calculators	2	group	
Recording sheet and two colored pencils	1 sheet, 2 pencils	student	
Class charts drawn on the board or on poster paper	2	class	

Estimated cost: 6 to 11 per class (estimate) (an estimate; A 2 lb (about 900 g) bag of dried beans, about \$3, gives roughly 2,000 beans, enough for 8 to 10 groups and reusable for years; cups and bowls are classroom stock or about \$3 for a sleeve of cups; printing one card page per group and a recording sheet of about 5 pages per student (about 160 pages for a class of 30) is about \$3 to \$5 at 2 to 3 cents a page.)

Safety

- Dried beans are a choking hazard and are not food: never put them in mouths, noses or ears. Raw dried kidney beans contain a natural toxin that only long boiling destroys, so no bean from the kit is ever eaten.

- Spilled beans are a slip hazard on hard floors; keep the cups over the desk and pick up spills right away.
- Wash hands after handling the beans. Use paper counters for any student with a legume allergy.
- No heat, flames, chemicals or sharp tools are used.

Teacher preparation and setup

1. Count about 150 beans into a bag for each group, or cut paper counters. Label the cups, the reserve cup and the supply bowl.
2. Print the rule card, the regrowth table and the five solution cards on one page per group; laminate if you can.
3. Draw two class charts: the Part B chart (one row each for the Part A village, B1 and B2) and the Part C chart (design, cost, lowest lake plus reserve, percent local, meets all criteria).
4. Assign Part B runs before class: in every group one pair runs B1 (slow growth, 1 fish per family every year) and the other pair runs B2 (slow growth, 2 fish per family from year 5).
5. Run years 1 and 2 of Part A yourself once, so you can model a year in under two minutes and check that the year 1 row on the sheet matches.

Investigation design

Independent variable	Part A: the shortfall rule (otters go hungry; the village imports). Part B: growth in the number of families versus growth in fish per family. Part C: the solution card or package of cards.
Dependent variable	Consumers each year, fish in the lake at the end of each year, fish imported, the lowest lake-plus-reserve count, and the percent of the village's fish that came from the lake or the farm.
Controlled	Starting lake of 40 fish and 4 consumers; The same regrowth table, the 4 hiding fish and the 60-fish limit; Twelve years per run; The same growth rule within each part
Trials	The model has no chance in it, so one careful run per condition gives its result; a second pair or group running the same condition catches counting errors.
Comparison	Otter rule versus village rule; B1 versus B2 versus the Part A village; each Part C design versus the village with no solution cards.

Student procedure

1. Session 1. Read the rule card and the regrowth table together. Before moving any beans, answer q1: predict how the otter run and the village run will differ.
2. Part A setup. Split into two pairs. Each pair puts 40 beans in its lake cup, sets 4 of them on its Reeds card (they are still in the lake but can never be caught) and writes 4 consumers for year 1. Pair 1 runs the otter rule; pair 2 runs the village rule. Both use the same growth rule.
3. Run one year with the four steps on the rule card: fish (take out 1 fish per consumer, never the 4 on the reeds); shortfall (otters that got no fish leave or die; the village records the missing fish as imports);

- regrow (count the fish left, look up the regrowth, add it from the supply, never above 60); grow (add newcomers only if every consumer ate). The rule checker reads each step aloud first.
4. The bookkeeper fills the row, and the rule checker confirms that fish at end = fish at start – caught + regrowth before the next year starts. Year 1 is already filled in on the sheet; both pairs should match it.
 5. Run 12 years, swapping lake keeper and bookkeeper after year 6. Then copy the other pair's consumers, lake counts and imports into the comparison table and graph both runs on one set of axes: consumers in one color, lake fish in the other, a solid line for the otter run and a dashed line for the village run.
 6. Part B. Reset each lake to 40 fish and 4 families. Both pairs now use the village rule with slow growth: add exactly 1 family each year. Pair 1 runs B1: every family needs 1 fish every year. Pair 2 runs B2: each family needs 1 fish in years 1 to 4 and 2 fish from year 5 on. Run 12 years and fill in the Part B table.
 7. Post the Part A village, B1 and B2 results on the class chart: the first year fish needed was more than the regrowth, the first year the lake ended below 20, fish imported in 12 years, and families and fish needed in year 12. Copy the class chart onto your sheet. Count the beans back into the bag.
 8. Session 2, Part C. Read the solution cards and the three criteria. Each pair chooses a design: one card, or a package of two cards costing 8 coins or less in total. Answer q2 before running.
 9. Reset the lake to 40 fish and 4 families and run the fast-growing village (the Part A village rule) for 12 years with your design's rule changes. Fill in the Part C table, tracking lake plus reserve at the end of every year and where every fish came from: the lake, the farm or imports.
 10. Fill in the totals row, check your design against the criteria and post it on the Part C class chart. If it failed, change one card and run again. Copy the class chart, count the beans back into the bag, and answer the analysis questions on your own.

Expected observations

- Part A reference run (both rules, years 1 to 10): consumers 4, 5, 6, 7, 8, 10, 12, 15, 18, 22; lake at end of year 46, 49, 51, 52, 52, 50, 48, 43, 33, 16. Year 11: 27 consumers but only 12 fish can be caught, lake ends at 6. Otters: 12 in year 12 and only 2 left for year 13. Village: 33 families in year 12 and 41 in year 13, with 15 and then 31 fish imported (46 in all).
- Part B reference runs (the first year fish needed was more than the regrowth: year 6 for the Part A village and B1, year 5 for B2): B1 never tips within 12 years (lake ends year 12 at 30 and falling; 15 families need 15 fish; nothing imported). B2: fish needed jumps from 7 to 16 in year 5, the lake ends year 7 at 21 and year 8 at 6, and imports total 105 fish by year 12 (15 families needing 30 fish).
- Part C reference results (lowest lake + reserve; percent local): no cards 6, 72%; Q 46, 60%; M 48, 67%; R 18, 83%; F 5, 98%; E 6, 93%. Designs that pass all three: Q+F (7 coins) 46, 78%; M+F (8) 47, 83%; M+E (6) 49, 78%; R+E (7) 27, 100%; F+E (8) 34, 100%. R+F works (21, 100%) but costs 9 coins.
- Groups that forget the 4 hiding fish crash the lake to zero, after which nothing regrows; groups that look up regrowth from the starting count instead of the fish left get a lake that never declines.

Likely difficulties

- Forgetting the 4 hiding fish and catching the lake down to zero. The Reeds card makes them visible; the rule checker asks 'how many can we catch?' every year.

- Looking up regrowth from the fish at the start of the year instead of the fish left after fishing. Insist that the lake keeper counts the cup after the catch.
- Adding newcomers to the otters in a year when some went hungry. Step 4 applies only when every consumer ate.
- Rounding newcomers: 1 for every 4 consumers, rounded down, but at least 1, so 27 families add 6 newcomers, not 7, and 5 families add 1.
- Part C bookkeeping: with card F, subtract the farm's fish from the need before fishing; with card R, the reserve is never in the lake cup but counts toward lake health; with cards Q and M together, the catch limit is 10.
- Time: if Part B runs late, stop at year 10. B2's lake has already ended a year below 20 by year 8, B1's never does within 12 years, and the year-12 families and fish needed can be worked out from the rules without moving beans.

Structured debrief

1. Put one group's two Part A lines side by side. Ask what the runs share (years 1 to 10 are identical) and where they split (year 11). Name the single rule that differs. Connect to slides 6 and 7: lynx cannot import hares; people import fish, grain and wood, so the local crash does not happen to us, but the demand lands on someone else's lake.
2. Read the Part B class chart. B2 tipped first, with the lake below 20 by year 8, even though in year 12 it had fewer than half as many families as the Part A village. Write total use = families × fish per family on the board and compute year 12 for each run (33, 15 and 30).
3. Turn the Part C chart into a ranking. No single card passes; five two-card designs pass, each with a different weak spot (imports, a thin lake-health margin, pollution from the farm). Ask which design a fishing family, a lake biologist and a village treasurer would each pick, and why.
4. Ask the year-20 question aloud (q11). Every passing design falls below 75 percent local once families reach the hundreds, and two of them also crash the lake. Engineering changes the impact per fish; it does not make a demand that keeps doubling sustainable.
5. Close on the model's limits: one species, no good or bad years, perfect rule-following, free and unlimited imports. Ask which limit would change the results most if it were removed, and why the otters in this model crash but do not cycle back like the lynx and hares.

Recording sheet: what students fill in

Lab 1 recording sheet: The Lake Can Give Ten

Each bean stands for a fish (think of it as a school of fish). Each round is one year. A **consumer** is one otter or one village family; each needs 1 fish a year unless a rule says otherwise. The lake regrows fish every year, but how many depends on how many are left. Fish are hard to grow back when few are left, and a crowded lake has little room for more.

Rule card: the four steps of every year

Step	Otter rule	Village rule
1. Fish	Take 1 fish per otter. The 4 fish on the reeds can never be caught.	Take 1 fish per family. The 4 fish on the reeds can never be caught.
2. Shortfall	Each otter that got no fish leaves or dies.	Missing fish are bought from far away. Record them as imported.
3. Regrow	Count the fish left. Add new fish from the regrowth table. Never more than 60.	Same as the otter rule.
4. Grow	Only if every otter ate: add 1 newcomer for every 4 otters (round down), at least 1.	Every family ate (lake or imports): add 1 newcomer for every 4 families (round down), at least 1.

Regrowth table

Fish left in the lake after fishing	New fish added
1 to 9	2
10 to 19	5
20 to 29	8
30 to 39	10
40 to 49	8
50 to 59	4
60	0

1. Prediction before Part A: the otter run and the village run start the same and use the same growth rule. How do you think the two runs will differ by year 12, and why?

Answer: Predictions vary. A strong prediction: the two runs will look the same while the lake has plenty of fish; once fish run short, the otters will fall because hungry otters leave or die, while the village keeps growing because it imports fish, and the lake shrinks in both runs.

Why: This is a prediction, so credit the reasoning rather than the outcome. Students who expect the village to grow without limit and the lake to be unaffected should revisit q5 and q6.

- States whether and how the runs will differ
- Gives a reason tied to food supply or the shortfall rule

Part A: your pair's run (circle one: otter rule / village rule)

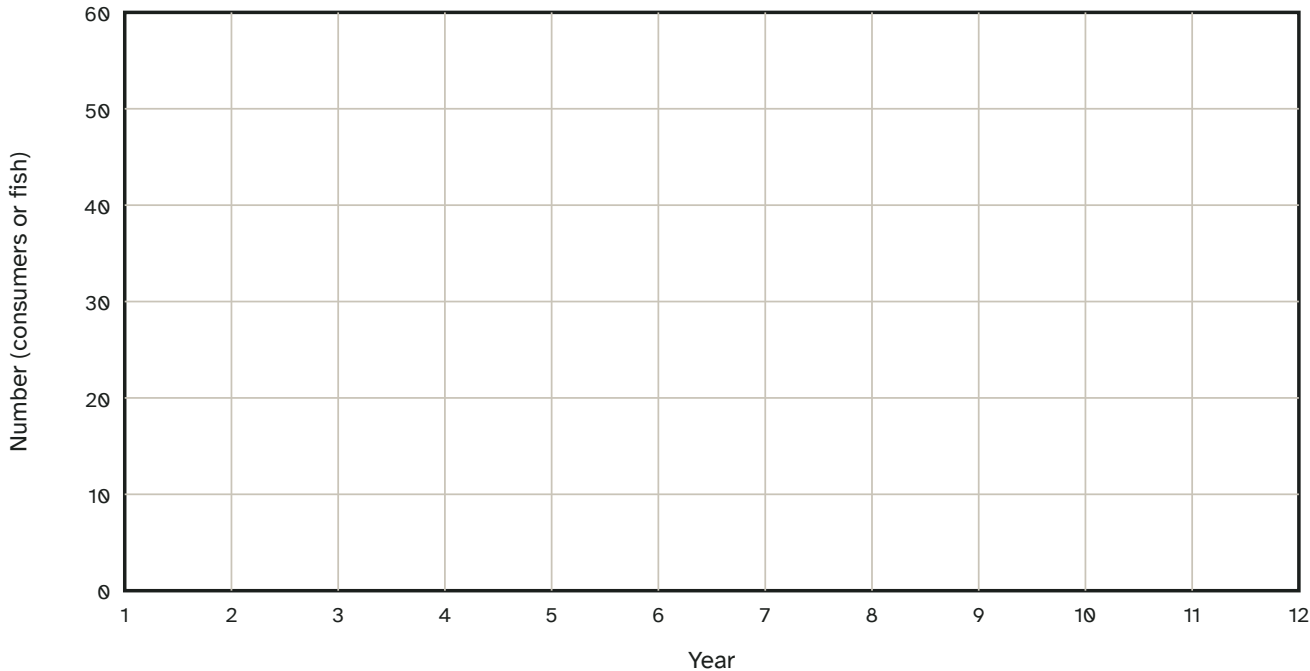
Year	Consumers at start	Fish needed	Caught from lake	Hungry otters or imported fish	Fish left after fishing	Regrowth added	Fish at end of year	Consumers next year
1	4	4	4	0	36	10	46	5

Year	Consumers at start	Fish needed	Caught from lake	Hungry otters or imported fish	Fish left after fishing	Regrowth added	Fish at end of year	Consumers next year
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								

Part A: both runs side by side

Year	Otters at start	Lake at end (otter run)	Families at start	Lake at end (village run)	Fish imported by the village
1	4	46	4	46	0
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

Part A: consumers and lake fish, otter rule and village rule



Part B: your pair's run (circle one: B1 / B2)

Year	Families	Fish per family	Fish needed	Caught from lake	Imported	Fish at end of year
1	4	1	4	4	0	46
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

Class chart, Part B: when did each lake tip?

Run	First year fish needed was more than regrowth	First year the lake ended below 20	Fish imported in 12 years	Families in year 12	Fish needed in year 12
Part A village (fast growth, 1 fish per family)					
B1 (1 new family a year, 1 fish per family)					
B2 (1 new family a year, 2 fish per family from year 5)					

Part C solution cards (budget: 8 coins)

Card	Cost (coins)	Rule change
Q: Catch limit	2	The village may take at most 10 fish a year from the lake. Any other fish it needs are imported.
M: Larger-mesh nets	3	Young and small fish slip through and grow up: add 2 to the regrowth every year. Big-mesh nets catch at most 12 fish a year. (With card Q, the limit is 10.)
R: No-fishing reserve	4	Before year 1, move 10 of the 40 fish into the reserve cup; they are never caught. After regrowth each year, add 2 fish from the supply to the lake (young fish swimming out). The reserve stays at 10.
F: Fish farm pond	5	Before anyone fishes, the farm supplies up to 6 fish to the village each year. Farm waste enriches the water: subtract 1 from the regrowth every year.
E: Ice house	3	With ice and drying racks, less fish spoils: fish needed = families minus 1 for every 4 families (round down).

Part C criteria (fast-growing village, 12 years) – 1. Lake health: the lake plus the reserve holds at least 20 fish at the end of every year. **2. Local supply:** at least 75 percent of the fish the village uses in 12 years come from the lake or the farm, not imports. Percent local = (fish from lake + fish from farm) ÷ total fish needed × 100. **3. Budget:** the cards cost 8 coins or less in total.

Class chart, Part C: which designs met all three criteria?

Design (cards)	Cost (coins)	Lowest lake + reserve	Percent local	Meets all three criteria?
No cards	0			

Analysis questions: answer key

3. Part A: in which year did the lake first end the year with fewer fish than it started with? Compare the fish caught that year with the fish that regrew.

Answer: Year 6. The lake started the year at 52, 10 fish were caught, 42 were left, and 42 fish regrow only 8, so the lake ended at 50. It was the first year the catch (10) was bigger than the regrowth (8). In year 5 the catch and regrowth were both 8, so the lake stayed at 52.

Why: A stock shrinks when the harvest is larger than what regrows that year. With 40 to 49 fish left, regrowth is 8, so 10 consumers are enough to tip it.

Also acceptable: Accept 'year 6, when demand passed regrowth' with the two numbers.

4. From year 6 to year 10 the lake lost more fish each year: 2, 2, 5, 10, then 17. Use the regrowth table to explain why the decline sped up, even though the lake had held steady for years.

Answer: The yearly catch kept rising (10, 12, 15, 18, 22) because consumers kept growing, while the regrowth stayed at 8 to 10 and then dropped to 5 once fewer than 20 fish were left. The gap between catch and regrowth grew from both sides, so each year's loss was larger than the last. A smaller lake has fewer adults to produce young, so the more it shrinks, the more slowly it refills: the decline feeds on itself.

Why: Full credit names both parts of the widening gap: rising demand and falling regrowth at low stock. This is the over-exploitation trap and an example of a small change causing a large one.

- Rising demand each year
- Regrowth falling as the stock shrinks, from the table
- The widening gap makes the decline speed up

5. Compare the otters and the village in years 11 and 12. What happened to each population, and which single rule made the difference?

Answer: In year 11 there were 27 otters but only 12 fish could be caught, so 15 otters went hungry and left or died; only 12 started year 12, and with just 2 catchable fish only 2 were left for year 13. The village had 27 families in year 11, imported 15 fish, grew to 33 families in year 12, imported 31 fish and grew to 41. The only rule that differs is step 2: hungry otters leave, while the village buys its missing fish from elsewhere.

Why: The runs are identical for ten years, so the shortfall rule alone explains the split. That mirrors the phenomenon: a wild population is limited by what its own ecosystem produces this year.

- Otter numbers with the crash
- Village numbers with imports
- Names step 2, the shortfall or import rule, as the single difference

6. The village never went hungry. In the real world, where would imported fish come from? Does importing remove the impact on ecosystems or move it? Explain.

Answer: From other lakes, rivers or the ocean, or from fish farms somewhere else, carried by truck, boat or plane. Importing moves the impact rather than removing it: those other ecosystems now supply the fish, and transport uses fuel. The village's total demand still lands on ecosystems, just not on its own lake.

Why: This links the model to the slide 7 idea that people draw on the whole planet. Credit any real source plus the 'moved, not removed' reasoning.

- A plausible real source of imported fish
- States that the impact moves to other ecosystems

7. Part B: use the class chart to compare B1, B2 and the Part A village in year 12 (families, fish needed, fish imported, first year below 20). Which pushed the lake down sooner, faster growth in families or more fish per family? Use numbers.

Answer: Year 12: the Part A village had 33 families needing 33 fish, had imported 46 fish, and its lake first ended below 20 in year 10. B1 had 15 families needing 15 fish, imported nothing, and its lake never ended below 20 (30 in year 12). B2 had 15 families needing 30 fish, had imported 105 fish, and its lake ended below 20 in year 8. More fish per family (B2) pushed the lake down sooner than faster growth in families, even with fewer than half the families of the Part A village.

Why: B1 and B2 have the same number of families every year; only the fish per family differs, so comparing them isolates per capita use. Comparing B2 with the Part A village shows that use per person matters as much as headcount.

- Uses numbers from all three runs
- Identifies B2 as tipping first (year 8 versus year 10)
- Explains that B1 versus B2 isolates fish per family

8. Total use = families × fish per family. Calculate year 12's total for the Part A village (33 families, 1 fish each) and for B2 (15 families, 2 fish each). How many families using 1 fish each would match B2's total? Show your work.

Answer: Part A village: $33 \times 1 = 33$ fish. B2: $15 \times 2 = 30$ fish. To match 30 fish at 1 fish per family takes $30 \div 1 = 30$ families, twice B2's 15.

Why: Doubling use per person has the same effect on total demand as doubling the number of people, which is the core of total use = population × per capita use.

Also acceptable: Accept 'about the same as the Part A village' if the student shows 30 versus 33.

9. Part C: which single cards met all three criteria? Which designs did? Give the numbers for one design that passed and one single card that failed.

Answer: No single card met all three. Q (catch limit) kept the lake healthy (lowest 46) but only 60 percent of fish were local; M (larger mesh) 48 and 67 percent; R (reserve) 83 percent local but lake health fell to 18; F (farm) 98 percent local but the lake fell to 5; E (ice house) 93 percent local but the lake fell to 6. Designs that passed: Q+F (7 coins, lowest 46, 78 percent), M+F (8 coins, 47, 83 percent), M+E (6 coins, 49, 78 percent), R+E (7 coins, 27, 100 percent) and F+E (8 coins, 34, 100 percent). R+F also met the two lake criteria (21, 100 percent) but cost 9 coins, over budget.

Why: Values are from running the card rules exactly; small counting slips in class may shift a number by one or two. The pattern is the point: limits protect the lake but raise imports, while supply and efficiency cards cut imports but do not protect the lake, so passing designs combine one of each.

- States that no single card passed
- Names at least one passing design with its numbers
- Names a failing single card with its numbers and the criterion it failed

10. Which design would you recommend to the village? Name the criterion it meets with the most room to spare, the one it meets most narrowly, and one tradeoff the village accepts with it.

Answer: Group-specific. Example: 'M+E (6 coins). Most room to spare: lake health, which never fell below 49 against a target of 20. Narrowest: local supply at 78 percent, only 3 points above 75. Tradeoff: big-mesh nets catch at most 12 fish a year, so by year 12 the village imports 13 fish that year from somewhere else.'

Why: Credit any passing design whose margins are read correctly from the run. Other good tradeoffs: the farm's waste lowers regrowth (F); the reserve closes part of the lake to fishing (R); a catch limit means buying fish (Q).

- Chooses a design that met all three criteria in class data
- Identifies the largest and smallest margin with numbers
- Names a real tradeoff of that design

11. The growth rule takes the village from 33 families in year 12 to 188 families in year 20. Predict whether the designs that passed at 12 years would still pass at 20 years, and explain what this suggests about engineering fixes when demand keeps growing.

Answer: No. By year 20 every design that passed at 12 years gets only about a quarter to a third of the village's fish locally (about 24 to 30 percent), far below 75 percent, because the need grows into the hundreds of fish a year while the lake and farm supply roughly the same amount as before. R+E and F+E also let the lake fall below 20 (to 18 and 5). Engineering fixes change how much each fish costs the ecosystem and buy time, but they cannot keep up with a demand that keeps growing; long-term success also needs the demand to level off, through slower growth, lower use per person or new supplies that do not depend on the lake.

Why: Figures come from extending the card rules to 20 years. Students do not need exact values; full credit predicts failure and explains why with growing demand versus a limited supply.

- Predicts that the designs fail by year 20
- Explains growing demand against a roughly fixed supply
- Draws a conclusion about the limits of engineering fixes

12. Name two ways this model is simpler than a real lake and its fishery, and say how each might change the results.

Answer: Any two, each with an effect. One species only: real lakes have many species and food-web effects, such as the snail-eating fish at Lake Malawi. No good or bad years: a drought or heat wave could crash the lake sooner. Everyone follows the rules: illegal fishing would weaken catch limits. Imports are free and unlimited: real imports cost money and fuel and can run short. The regrowth table is invented: a real stock might tip sooner or later.

Why: The goal is to treat the model as a tool with stated limits, not as a prediction for a real lake.

- Two specific differences from a real lake
- A plausible effect of each on the results

Individual evidence of learning

Each student submits the Part A table, comparison table and graph, their pair's Part B and Part C tables, copies of both class charts, and their own answers to q1 to q12. Questions q5 and q6 are the evidence for the wild-versus-human contrast, q7 and q8 for population times use per person, and q9 to q11 for evaluating competing solutions against criteria.

Assessment criteria

Criterion	Proficient looks like
Running the model accurately	Tables follow the rules (hiding fish, regrowth from fish left, 60-fish limit, newcomers only when all ate) and every row balances; Part A matches the reference run.
Explaining the tipping point	Explains that catching more than the regrowth shrinks the stock and that a smaller stock regrows less, so decline speeds up (q3, q4).
Wild versus human	Names the shortfall rule as the only difference between the runs and explains imports as impact moved to other ecosystems, not removed (q5, q6).
Population times use per person	Uses year-12 totals to show that doubling fish per family raised demand about as much as having twice as many families (q7, q8).
Evaluating designs	Uses class data to say which designs met all three criteria, names a tradeoff, and recognizes that a demand that keeps growing eventually defeats every package (q9 to q11).

Accessibility adaptations

- Give students who need support a rule card drawn as a four-box flowchart and a regrowth table with each band in a different color.
- Use large lima beans or counters and a muffin tin or egg carton for the lake, so fish can be counted by cup; this helps students with low vision or limited fine-motor control.
- Bookkeepers may use a calculator for every row, and a partner can read the numbers aloud.
- Part A can be run as a whole-class movement game, with students as otters or families stepping into a lake circle for a bean each year and the teacher as bookkeeper.

Low-cost alternative

No beans? Give each pair a paper strip of 60 numbered boxes per lake and shade boxes in and out with pencil as fish are caught and regrow, or keep tally marks on a mini whiteboard. Every rule works the same; only the token changes.

Model limitations

The lake has one fish species, an invented regrowth table, no good or bad years, perfect rule-following, a refuge of exactly 4 fish and imports that are unlimited and free; real fish stocks vary with weather, disease and food, and real catch limits are sometimes broken. The otters crash but do not recover within 12 years, unlike the repeating lynx and hare cycles, because real cycles involve time lags, many predators and prey that recover from refuges, which this model leaves out. The solution cards are simplified versions of real tools (catch limits, mesh rules, marine reserves, aquaculture and cold storage) with invented numbers, so the results show patterns rather than predictions for any real lake. This activity has not been physically tested with students by the authors; the reference results come from applying the rules exactly.

Teacher notes

The model is deterministic, so a group that follows the rules exactly will match the reference runs; most mismatches come from forgetting the 4 hiding fish, looking up regrowth before fishing, or rounding newcomers up. Part A reference (both rules through year 10; years 11 and 12 differ): year 1 caught 4, left 36, regrowth 10, end 46; year 2 caught 5, left 41, +8, 49; year 3 caught 6, 43, +8, 51; year 4 caught 7, 44, +8, 52; year 5 caught 8, 44, +8, 52; year 6 caught 10, 42, +8, 50; year 7 caught 12, 38, +10, 48; year 8 caught 15, 33, +10, 43; year 9 caught 18, 25, +8, 33; year 10 caught 22, 11, +5, 16; year 11 needed 27, caught 12, left 4, +2, 6; year 12 caught 2, left 4, +2, 6. Otters: 15 hungry in year 11 and 10 hungry in year 12, so 12 otters start year 12 and 2 start year 13. Village: imports 15 and 31. B1 lake ends years 1 to 12 at 46, 49, 51, 52, 52, 51, 49, 48, 46, 43, 37, 30. B2 lake ends at 46, 49, 51, 52, 46, 36, 21, 6, 6, 6, 6, 6, with imports 5, 22, 24, 26 and 28 in years 8 to 12. Part C reference results are in the expected observations; the total fish needed in 12 years is 167 for every design without card E and 130 with it. The lowest end-of-year lake count is what criterion 1 tests; it can rise above 60 when a reserve is added because the reserve is counted separately.