

Clear the Flood: Design, Test and Combine a Model Bridge

Investigation question: Which bridge features keep a road open through a flood with floating logs, and can a bridge that combines the best features of several tested designs beat every one of them?

Engineering design challenge

Groups of 4

2 sessions

Setup 10 · Activity 90 · Cleanup 10 min

MS-ETS1-2 · practice

MS-ETS1-3 · practice

MS-ESS3-2 · practice

Scientific purpose

Groups use a simulated 40-year record of a model creek to work out the yearly chance of three flood sizes, choose the flood their bridge must survive based on what the road serves, and build a bridge across a sand channel in a stream tray under a 20-point budget. Every bridge faces the same three tests: a small flood, a design-size flood with ten floating 'logs', and a record flood with logs. Groups measure peak water, overtopping, logs trapped, scour at the footings and whether the bridge still holds 200 grams. In the second session the class scores every design in a decision matrix, each group borrows at least two features from other groups' bridges, and the combined version 2 is retested.

Why this helps students with this chapter

Most students imagine a flood knocking a bridge down with a wall of water. Real flood failures are usually quieter and more instructive: logs and branches pile up against piers until the current shoves the bridge sideways, as happened to the Highway 101 bridge over the Klamath River in December 1964, and fast water digs scour holes around the footings until they sink. A stream tray makes both visible in a few seconds. Choosing a design flood from a record forces students to treat flood risk as a chance, not a schedule, and the class decision matrix shows that no single bridge wins every test, which is why combining the best features works.

Standards connections

MS-ETS1-2 (practice, evaluating competing bridge designs systematically against criteria and constraints): Students score every tested design on the same criteria (overtopping, logs trapped, scour, load) and constraints (budget, deck height) in a class decision matrix built from shared test data. The criteria are supplied, so this practices the PE.

MS-ETS1-3 (practice, identifying the best characteristics of several designs and combining them into a better one): After the matrix, each group names the strongest feature of at least two other designs, combines them in version 2 and retests it, then reports whether the combination beat every original on each criterion, mirroring the three combined DART fixes in the lesson.

MS-ESS3-2 (practice, using flood-frequency data to set the design flood for a mitigation structure): Students turn a simulated record of yearly peak flows into yearly chances and expected numbers of floods over a bridge's life, and use them to choose which flood the bridge must survive. This uses hazard frequency data to inform a technology, but the record is simulated and short, so the role is practice.

Roles (rotate each session)

- **Project manager:** Keeps the budget sheet, checks that the design meets the constraints before building, and runs the 20-minute build clock.
- **Builder:** Leads construction from the sketch and places the bridge at the marked site with its footings set the same way for every test.
- **Flood operator:** Sets up the flood bottle, fills it to the 1.5 L line, peels the tape on the count, and drops the ten logs into the channel in the first 5 seconds.
- **Gauge reader and recorder:** Reads the peak water level on the upright ruler, measures scour at the footing pins and bridge movement, runs the load test and records every result.

Materials

Item	Quantity	Per	Note
Stream-tray station: a school stream table or a long plastic under-bed storage box (about 80 x 45 x 15 cm)	1 per two groups (4 per class)	class	The upstream end is raised about 4 cm on a book.
Washed play sand (dried Lab 1 sand works)	about 12 L (about 19 kg) per station	class	
Flood bottles: 2 L soda bottles with the bottoms cut off and 2, 4 or 6 holes about 5 mm wide drilled in the caps, labeled Small, Design-size and Record	1 set of 3 per station	class	Teacher cuts and tapes the cut edges.
Channel template: a block of wood or a carton about 8 cm wide	1 per station	class	
Pitcher and 1 L measuring jug	1 each per station	class	
Bucket and cup for bailing the 'lake' at the low end	1 each per station	class	
Craft sticks	about 25	group	
Drinking straws	about 10	group	
Blunt wooden skewers (points snipped off)	6	group	
Masking tape	1 roll	group	
Modeling clay	about 100 g	group	
Aquarium gravel for armoring footings	about 250 mL	group	
Logs: twigs or broken craft sticks 4–6 cm long	10	group	
Load: 80 pennies (about 200 g) sealed in a small zip bag	1 bag	group	A U.S. penny is 2.5 g; standard masses also work.
Clear 30 cm ruler, toothpicks and a fine marker (gauge and scour pins)	1 ruler, 6 toothpicks	group	

Safety goggles	1	student	
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Estimated cost: 40 to 80 per class (estimate); about 15 to 25 if the school has stream tables and reuses the Lab 1 sand (an estimate; Four under-bed storage boxes at about \$10-15 each, a box of 1,000 craft sticks about \$8, straws about \$3, modeling clay about \$5, a 2 lb bag of aquarium gravel about \$5, plus one extra 50 lb bag of play sand about \$7 if Lab 1 sand is not enough. Soda bottles, rulers, buckets, pennies and goggles come from the classroom or recycling. Typical U.S. retail prices.)

Safety

- Wear goggles while pouring floods and releasing logs; sandy water can splash into eyes.
- Water on the floor is a slip hazard. Keep a towel under each station, bail the lake into the bucket after every test, and wipe spills at once.
- A filled stream box weighs 20 kg or more. Never lift or carry a box with sand in it; set stations up where they will stay.
- Skewers have their points snipped off, and the cut bottle edges are taped, but handle both with care. Report any sharp edge to the teacher.
- Keep phones, laptops and electrical cords away from the water. Use a phone to film the peak only from outside the splash zone, in a plastic bag if possible.
- Do not pour sand or sandy water down sinks. Let the bucket settle, pour the clear water outside, and return the sand to the station. Wash hands after the lab.

Teacher preparation and setup

1. Set up each station: fill the box with about 12 L of damp sand to about 4-5 cm deep over the upper 65 cm, leaving the lowest 15 cm empty as a 'lake' to catch flood water. Raise the upstream end about 4 cm on a book.
2. Pull the channel template down the middle of the sand to carve a channel about 8 cm wide and 3 cm deep, and mark the bridge site with tape on the box rim 30 cm from the upstream end. Mark a second site for the second group, 20 cm farther downstream, so two bridges can stand at one station without one feeding logs to the other during the same test.
3. Make the flood bottles: cut the bottoms off 2 L bottles, cover the cut edge with tape, and drill 2, 4 or 6 holes about 5 mm across in the caps. Test each one with 1.5 L held cap-down over the channel head: the Small flood should stay in the channel, the Design-size flood should just reach the tops of the banks, and the Record flood should spread across the floodplain. Adjust the hole count if your sand behaves differently.
4. Print the stream record, the importance cards (only road to a hospital, school bus route, farm road, park footbridge) and the cost sheet. Assign importance cards so every card is used at least once.
5. Bag 80 pennies per group, snip the points off the skewers, and cut or collect ten 4-6 cm twigs per group.
6. Practice one full test yourself (fill, release, logs, read, measure scour, load, bail, smooth the channel) so you can model it in two minutes.

Investigation design

Independent variable	The bridge design: deck height, number and placement of piers, span type, footing armor and materials.
Dependent variable	Peak water at the bridge, overtopping (yes or no), logs trapped out of 10, deepest scour at a footing (mm), bridge movement (mm) and the 200 g load test after each flood.
Controlled	Same channel shape, cut with the same template and smoothed before every test; Same tray slope and bridge site; Same flood bottles filled to the same 1.5 L line for each flood size; Same ten logs released at the same point and time; Same 200 g load placed at mid-span for 10 seconds
Trials	Each version faces each flood once; the class pools results from about eight designs, and version 2 is retested on the two harder floods. If time allows, repeat Test 2 to check for a fluke.
Comparison	Class decision-matrix totals for every version 1 design, and each group's version 2 against its own version 1 and against the best version 1 on each criterion.

Student procedure

1. Session 1. As a group, read the stream record and answer q1: the yearly chance of each flood size. Read your importance card and choose your design flood in q2, using the yearly chances and the number of floods expected in a 30-year bridge life.
2. Read the criteria and constraints on the recording sheet and write your group's targets in the criteria table. Then sketch your bridge in the drawing box, label every feature, and add up its cost. The project manager checks the budget (20 points or less), the deck height (underside no more than 7 cm above the channel bed) and the length (at least 16 cm).
3. Build version 1 in 20 minutes or less, using only kit materials.
4. At the station, smooth the channel with the template and set the bridge at your site. Push a toothpick into the sand beside each footing and mark the sand level on it. Push the clear ruler upright into the channel bed 5 cm upstream of the bridge as a water gauge. Tape a mark on the rim beside each end of the bridge.
5. Test 1, Small flood, no logs: tape the cap holes of the Small bottle, fill it to the 1.5 L line, hold it cap-down over the head of the channel, and peel the tape. The gauge reader reads the highest water level on the ruler (film it if you can) and watches for water touching the deck.
6. After the flow stops, record overtopping, scour (distance from each toothpick mark down to the new sand surface, in mm) and movement (distance each end moved from its rim mark). Place the 200 g bag at mid-span for 10 seconds: it passes if nothing breaks and the deck does not touch water or sand. Bail the lake, smooth the channel, refill any scour holes and reset the toothpicks.
7. Test 2, Design-size flood with logs: repeat with the Design-size bottle, and drop all ten logs into the channel about 10 cm upstream of the bridge in the first 5 seconds. Count the logs trapped against the bridge when the flow stops, then record everything else as in step 6.
8. Test 3, Record flood with logs: repeat with the Record bottle and the ten logs. Post your results on the class results chart.

9. Session 2. Copy the class results into the decision matrix. Score every design 0, 1 or 2 on each criterion (0 = misses the target, 1 = meets it, 2 = meets it with a clear margin) and total the scores. Write the best feature of each top design in the last column.
10. Answer q3: choose at least two features from other groups' designs to combine with your own. Redesign within the same constraints, sketch the changes, and build version 2.
11. Retest version 2 with Test 2 and Test 3 exactly as before and record the results in the version 2 table.
12. Post version 2 results, clean the station, and answer q4 through q10 individually.

Expected observations

- Expected, not yet tested: the Small flood stays in the channel and rarely harms any bridge; the Design-size flood reaches the bank tops and overtops low decks; the Record flood spreads onto the floodplain, overtops most decks under about 5 cm and pushes poorly anchored bridges sideways.
- Logs jam against piers in the channel and against low decks; open spans with high decks pass most logs.
- Scour holes form beside piers and at bridge ends that narrow the channel, often 5-15 mm deep in the Record flood; gravel armor around a footing visibly reduces the hole.
- No version 1 design meets every criterion within budget in most classes; version 2 designs that borrow an open span and footing armor usually improve on both debris and scour.

Likely difficulties

- Floods vary if bottles are filled to different levels or held at different heights. Mark the 1.5 L line and hold the cap 2-3 cm above the channel head every time.
- Groups forget to smooth the channel and reset scour pins between tests, so scour adds up across tests. Make the reset part of the gauge reader's checklist.
- Reading the peak water level is hard in a few seconds. Film the gauge on a phone and pause the replay, or have two students read and average.
- Bridges that are simply heavy (lots of clay) survive by weight, which hides design differences. Count clay in the budget and remind groups that heavier is not always better: real foundations sink in scour holes.
- Two groups per station can mean waiting. Have the waiting group measure and record for the testing group, then swap; plan about 3 minutes per test.

Structured debrief

1. Build the decision matrix on the board from the posted results and circle the top two or three totals. Ask what the winners share. In most classes the answer is fewer or no piers in the channel and a higher deck: debris passes under an open span, and water does not speed up around a pier.
2. Ask each group to read one version 2 result against its version 1. Collect which combined features helped most. Make the ETS1-3 point explicit: the best version 2 designs usually borrowed one feature for debris (open span), one for scour (gravel armor around the footings) and kept their own cheapest deck, the same logic as the three combined DART fixes.

- Return to the stream record. Ask why the hospital-road groups chose the record flood even though it happened in only 1 of 40 years: over 30 years the expected number is close to one, and failure would cut off emergency care. Tell students real highway bridges are designed for rare floods, often one with about a 1 percent yearly chance, and engineers check what an even rarer flood would do to the foundations.
- Connect to California. The 1964 Klamath bridge failed with logs piled against it; the replacement crosses the river in a different place. Scour around foundations is the most common cause of bridge failures in the United States, which is why inspectors check bridges after big floods. Close by asking what data a county would want before rebuilding a bridge: a long flow record, debris loads, and the scour depth reached in past floods.

Recording sheet: what students fill in

Lab 2 recording sheet: Clear the Flood

Your bridge carries a road across Model Creek. Floods in the tray are made with flood bottles: more holes in the cap means a faster, higher flood. Logs are twigs released upstream. The tables below come from an imagined record of the creek.

Model Creek: 40 years of yearly highest flows

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

Flood size	Flood bottle	Years in which the year's highest flow reached at least this size (out of 40)
Small: stays in the channel	2 holes	22
Design-size: reaches the bank tops	4 holes	4
Record: spreads across the floodplain	6 holes	1

Teaching dataset for an imagined creek, invented for this lab; not a real stream record.

- For each flood size, calculate the chance that it happens in any one year (years reached divided by 40, as a percent). Show your work.

Answer: Small: $22 / 40 = 0.55 = 55$ percent per year. Design-size: $4 / 40 = 0.10 = 10$ percent per year. Record: $1 / 40 = 0.025 = 2.5$ percent per year.

Why: The yearly chance is estimated as the fraction of years in the record in which the yearly peak reached that size.

Also acceptable: Accept the W5 ranking method, $T = (n + 1) / m$ with $n = 40$: $41 / 22$, $41 / 4$ and $41 / 1$ give yearly chances of about 54, 10 (9.8) and 2.4 percent, if the method is shown.

2. Our importance card: _____. Which flood will our bridge be designed to survive, and why? Use the yearly chances and what the road serves.

Answer: Depends on the card. Hospital road: the Record flood, because even a 2.5 percent yearly chance gives close to one such flood in 30 years and losing the road could cost lives. School bus route or farm road: the Design-size flood (10 percent per year, about 3 in 30 years), checking what the Record flood would do. Park footbridge: the Small or Design-size flood, because closing it occasionally harms little and a cheaper bridge is acceptable.

Why: Credit any choice that uses the yearly chance and the consequences of failure together.

- Names a design flood
- Uses a yearly chance from q1
- Connects the choice to what the road serves

Criteria and constraints: our targets

Criterion or constraint	Requirement	Our target or plan	How we will measure it
C1 Overtopping	Deck not overtopped in our design flood		
C2 Stays put and carries load	Moves less than 5 mm and holds 200 g after our design flood		
C3 Debris	Traps no more than 3 of 10 logs		
C4 Scour	Deepest scour beside any footing less than 5 mm		
Budget	20 points or less (stick, straw, skewer or 10 cm tape = 1; clay ball or scoop of gravel = 2)		
Deck height	Underside no more than 7 cm above the channel bed		
Length	At least 16 cm, so both ends rest on the banks		

-  Sketch version 1 from the side and from above. Label the deck height, any piers, the footings and any armor, and write the cost of each part and the total.

Answer: A side and top view with deck height, piers (if any), footings, armor and part costs labeled, totaling 20 points or less, with a deck underside no more than 7 cm above the bed and a length of at least 16 cm.

Why: The sketch is the plan the project manager checks against the constraints before building.

- Two views
- All features labeled
- Cost per part and total shown, within budget
- Deck height and length within the constraints

Version 1 test results

Test	Peak water at gauge (cm)	Overtopped? (Y/N)	Logs trapped (of 10)	Deepest scour (mm)	Bridge moved (mm)	Held 200 g? (Y/N)
1 Small flood, no logs						
2 Design-size flood + logs						
3 Record flood + logs						

Class decision matrix (score each criterion 0, 1 or 2; use Tests 2 and 3)

Group and design	C1 Overtopping	C2 Stays put and load	C3 Debris	C4 Scour	Within budget? (Y/N)	Total	Best feature
1							
2							
3							
4							
5							
6							
7							
8							

3. Name at least two features from other groups' designs that you will combine with your own in version 2. For each, give the evidence from the matrix that it works and the cost it adds.

Answer: Example: 'We will use Group 3's single open span with no pier in the channel, which trapped 1 of 10 logs while our two-pier design trapped 7 (adds about 3 points for a longer truss), and Group 6's gravel armor around the bank footings, which kept scour to 2 mm (2 points). We will drop one of our two clay footings to stay within 20 points.'

Why: Each borrowed feature must be backed by matrix evidence and costed.

- At least two features from other groups
- Evidence from the class data for each
- Cost of each change and a plan to stay within budget

Version 2 test results

Test	Peak water at gauge (cm)	Overtopped? (Y/N)	Logs trapped (of 10)	Deepest scour (mm)	Bridge moved (mm)	Held 200 g? (Y/N)	Cost (points)
2 Design-size flood + logs							
3 Record flood + logs							

Analysis questions: answer key

4. Which design feature made the biggest difference to the number of logs trapped? Support your answer with class data from at least two designs.

Answer: Expected: the number of piers in the channel, together with deck height. Designs with no pier in the channel and a deck at 5-6 cm trapped few logs (for example 1 of 10), while low designs with two piers trapped most (for example 7 of 10), because logs catch between piers and against low decks.

Why: Students should compare at least two designs that differ mainly in the feature named.

- Names one feature
- Cites numbers from at least two designs
- Explains how the feature catches or passes logs

5. Where was scour deepest in the class tests, and why? Use the idea of how water speeds up as it squeezes past an obstacle or through a narrow opening.

Answer: Deepest beside piers in the channel and at bridge ends that stuck into the channel. The same amount of water must squeeze past a narrower space, so it speeds up and swirls around the obstacle; faster water can lift and carry more sand, so it digs a hole at the base. Logs jammed against piers made the opening even narrower and the scour deeper.

Why: Scour is driven by local acceleration and swirling flow around obstructions; this is the main reason real bridges fail in floods.

- Locates scour at piers or constrictions
- Explains faster water around obstacles
- Links faster water to moving more sand

6. A real bridge is expected to last about 30 years. Using your answers to q1, about how many design-size floods and how many record-size floods should it expect in that time? Show the calculations. Does 'record flood' mean it will not happen during the bridge's life?

Answer: Design-size: $0.10 \times 30 = 3$ floods expected in 30 years. Record-size: $0.025 \times 30 = 0.75$, so close to one. A record flood is rare in any one year but quite possible during the bridge's life; 'record' only means it was the largest in the 40 years observed, and a larger flood could still come.

Why: Expected number = yearly chance x number of years. Students should see that a rare flood is not an impossible one.

Also acceptable: Accept 'about 3' and 'about 1'. Students who compute the chance of at least one record flood ($1 - 0.975^{30}$, about 53 percent) earn extra credit.

7. Compare your version 1 and version 2 results. Which criteria improved, which stayed the same or got worse, and did the combined design beat every version 1 design on every criterion? Use numbers.

Answer: Group-specific. Example: 'Version 2 trapped 1 log instead of 7 and scour fell from 12 mm to 3 mm, and it held 200 g after both floods; but it cost 20 points instead of 14 and was still overtopped in the Record flood. It beat every version 1 design on debris and tied the best on scour, but Group 4's high arch kept a drier deck in the Record flood.'

Why: Full credit compares criterion by criterion with numbers and judges honestly whether the combination beat every original.

- Compares at least three criteria with numbers
- Names what improved and what did not
- Judges against the best version 1 designs, not only its own

8. Describe one trade-off the class found, for example between deck height, cost and the length of approach ramps, or between piers that support the deck and piers that catch logs. How would you decide which side of the trade-off to choose?

Answer: Example: a higher deck avoided overtopping but cost more and in a real road would need longer, costlier approach ramps; piers stiffened the deck for the load test but caught logs and caused scour. Decide by ranking the criteria for the road's use: for a hospital road, staying open in the record flood outweighs cost; for a footbridge, low cost may win and an occasional closure is acceptable.

Why: Students must name both sides of a trade-off and a decision rule tied to criteria.

- Names a real trade-off from class data
- Explains both sides
- Gives a reasoned way to choose

9. In December 1964, huge logs carried by the flooding Klamath River battered the Highway 101 bridge until spans on its south end washed out. Using your class data, describe two design changes that would have lowered that risk, and one reason your tray results cannot predict exactly what a real river would do.

Answer: Changes: remove piers from the main channel by using a longer span, so logs pass through; raise the deck and widen the opening so floodwater and debris pass under it; armor and deepen the footings against scour. Limit: the tray is not to scale, its sand is uniform and scours in seconds, real logs are whole trees, and a real flood lasts days with debris arriving in waves, so the tray shows which direction a change helps but not how much.

Why: The answer should draw on class evidence for debris and scour and state a real model limitation.

- Two design changes supported by class data
- One specific model limitation

10. Explain why engineers would design the only road to a hospital for a rarer, larger flood than a park footbridge. Use the words criteria, risk and cost.

Answer: Losing the hospital road for even a few days risks lives, so the risk of failure there is the most serious; that sets a stricter criterion, surviving the rare record flood. Meeting it costs more (a longer span, a higher deck, deeper footings), and the community accepts that cost because of what is at stake. A park footbridge failing causes little harm, so a cheaper design for a more common flood is a sensible criterion.

Why: Students must connect the consequence of failure to the criterion and the cost.

- Uses 'criteria', 'risk' and 'cost' correctly
- Explains that more serious consequences justify a stricter criterion and a higher cost

Individual evidence of learning

Each student submits the recording sheet (q1, q2, the criteria table, the version 1 sketch, results tables, the class matrix and q3) and answers to q4 through q10. The matrix and q3 and q7 are the evidence for systematic evaluation and for combining the best features; q1, q2, q6 and q10 show flood data informing the design flood.

Assessment criteria

Criterion	Proficient looks like
Using flood data	Correct yearly chances (55, 10 and 2.5 percent) and expected numbers over 30 years (about 3 and 0.75), and a design-flood choice justified by the road's importance (q1, q2, q6, q10).
Systematic evaluation	Matrix scored consistently from the posted data, with every design checked against every criterion and the budget (ETS1-2).
Combining features	Version 2 combines at least two features from other designs, each chosen with evidence, and the retest is compared with numbers to version 1 and to the best originals (q3, q7).
Explaining failure	Explains debris jams and scour in terms of piers, openings and faster water (q4, q5, q9).
Trade-offs and limits	Describes a real trade-off and how to decide it, and names at least one limit of the tray model (q8, q9).

Accessibility adaptations

- Provide a parts kit pre-counted to 20 points and a picture glossary of bridge parts (deck, pier, footing, abutment, span, armor).
- Students with limited fine-motor control can be project manager or gauge reader; partners build to their directions.
- Offer a printed side-view grid for the sketch, and accept a photo of the built bridge with labels added as the drawing.
- For students who struggle with fractions and percents, give a 'divide by 40' strip ($1/40 = 2.5$ percent) for q1 and a worked example for q6.
- Keep stations at table height with clear space around them for students using wheelchairs or walkers.

Low-cost alternative

If storage boxes are not available, use one shared stream tray at the front: each group builds and the class runs the tests as a demonstration, two groups per period while the others score designs from the posted data. A 1 m length of vinyl rain gutter with an end cap, filled with sand and tilted, makes a narrower channel for about \$10; scale the bridge length and deck height to fit it.

Model limitations

This activity has not been physically tested by the authors; the expected observations are predictions, and the flood bottles must be tuned to each tray. The tray is not to scale: its sand is uniform and loose, so scour

happens in seconds rather than over hours, and real riverbeds include gravel, clay and bedrock. Real floods last hours or days, carry whole trees and sediment, and rise and fall more gradually than a 1.5 L bottle. Model bridges are light and rest on the sand, while real bridges sit on deep foundations. The 40-year record is invented and short; real design floods come from much longer records and statistical estimates.

Teacher notes

Tune the three flood bottles before class so the Small, Design-size and Record floods behave as described; this matters more than any other prep step. Score the matrix from posted data only, so groups cannot argue their own results upward. If time is short in session 1, skip Test 1 for all groups; Tests 2 and 3 carry the analysis. For q6, the expected-number method is the target; the 'at least one' calculation is an extension. Real bridge design uses much longer records and statistical estimates, and foundations reach below the deepest expected scour; say so in the debrief.