

Tilt, Soak, Slide: When Does a Model Hillside Fail?

Investigation question: How does the amount of water in sand change the slope angle at which a model hillside fails, and can keeping rain out of a slope or letting it drain away delay the failure?

Physical model

Groups of 4

2 sessions

Setup 8 · Activity 85 · Cleanup 12 min

MS-ESS3-2 · practice

MS-ESS2-2 · supports

MS-ETS1-2 · supports

Scientific purpose

Students build a bed of sand in a lined tray and raise one end slowly until the sand fails, measuring the angle from the height of the raised end. Each group tests two of five water contents, from bone dry to saturated, three times each, and the class pools the results into one graph. In the second session groups rain on a damp slope held at 30 degrees, first bare and then with one mitigation (a plastic cover with a gutter, buried drains, or a toe wall), and count how much rain each slope takes before it fails. The data show that a little water strengthens sand while saturation weakens it, which explains why slopes fail at the end of long wet spells and why engineers fight landslides by managing water.

Why this helps students with this chapter

Students usually think water 'greases' a slope, so any water is bad. Damp sand standing at a steep angle and saturated sand sliding at a gentle one is a surprise they can see and measure, and it forces a better explanation: water films pull grains together, while water filling every gap lightens the grain-to-grain grip and adds weight. Measuring angles turns 'steep' and 'wet' into numbers, the same move scientists make when they map landslide potential. The rain test then links the cause to the cure: if water is the trigger, keeping it out or letting it drain should help, which is exactly how La Conchita's walls and Portuguese Bend's dewatering wells differ.

Standards connections

MS-ESS3-2 (practice, analyzing data on the conditions that trigger slope failure and using them to judge mitigation): Students analyze pooled failure-angle data and rain-to-failure counts to identify the conditions that make slopes fail, then use them to judge which mitigation works and what a landslide watch should monitor. The data come from a model, not from records of real hazards, so this builds toward the PE rather than assessing it.

MS-ESS2-2 (supports, a rapid, small-scale surface change and the threshold that sets it off): The tray shows a slope staying put for a long time and then changing in seconds once a threshold of angle or water is crossed, a small-scale example of the sudden surface change the clarification statement describes.

MS-ETS1-2 (supports, a first, informal comparison of mitigation designs): Session 2 compares three slope mitigations against one criterion, rain taken before failure, using class data. It previews the fuller systematic evaluation in Lab 2 and Lab 3.

Roles (rotate each session)

- **Lifter:** Raises the upper end of the tray slowly and evenly, about 1 cm every 5 seconds, and holds it still when the Watcher calls.
- **Reader:** Holds the ruler upright at the raised end and reads the height of the tray's bottom edge at each call, to the nearest 0.5 cm.
- **Watcher and timer:** Counts the 5-second steps aloud, calls 'crack' at the first crack or rolling grains and 'fail' when sand passes the tape line, and describes the kind of movement.
- **Recorder:** Writes every reading, converts heights to angles with the table, computes the means and posts them on the class chart.

Materials

Item	Quantity	Per	Note
Shallow plastic tray or disposable aluminum roasting pan, about 30 cm long, 20-25 cm wide and at least 5 cm deep	1	group	Measure the length of the tray's bottom, from the edge that rests on the table to the edge under the ruler; the height table assumes 30 cm.
Non-slip rubber shelf liner cut to fit the tray bottom	1 piece	group	Gives the sand a rough base so the bed does not skid on smooth plastic.
Washed play sand, premixed by the teacher in sealed 1-liter bags at water levels A-E	2 bags for session 1, 2 bags of level B for session 2	group	About 6.5 kg in all; play sand is reused after drying.
30 cm ruler, plus a second ruler or straightedge for leveling	2	group	
Masking tape and a marker	1 roll shared	group	
Stack of books or wooden blocks to prop the tray at 30 degrees	enough to reach 15 cm	group	
Rain cup: a clear plastic cup with about 12 pushpin holes in the bottom	1	group	Teacher pokes the holes ahead of time.
100 mL graduated cylinder or measuring cup	1	group	
Mitigation kit: plastic wrap and an index card (cover and gutter), 3 drinking straws and a pushpin (drains), or 8 craft sticks and tape (toe wall)	1 assigned kit	group	
Spoon or scoop, paper towels and a bucket for used sand	1 each	group	
Safety goggles	1	student	

Class chart (poster or board) for group means	1	class	
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Estimated cost: 30 to 55 per class (estimate) (an estimate; Three 50 lb bags of washed play sand at about \$6-8 each, a roll of non-slip shelf liner about \$6, zip bags about \$4, and disposable roasting pans at about \$2 each if the school has no trays. Rulers, cylinders, cups, straws, craft sticks and goggles are classroom stock. Prices are typical U.S. retail estimates; the sand is reused for Lab 2.)

Safety

- Wet sand is heavy: a tray with a liter of saturated sand weighs about 2 kg, and the bucket of used sand much more. Keep trays low on the tabletop and carry buckets with two people.
- Wear goggles throughout. Sand can fly when a slope fails, and grit in the eyes is the most likely injury. Never blow on sand to clear it.
- Use washed play sand, not crushed silica, construction sand or sandblasting sand. Keep the sand damp where possible and do not pour dry level A sand from a height; fine dry dust can irritate lungs, so a student with asthma should handle only damp bags.
- Spilled sand and water make floors slippery. Work over paper towels and sweep or wipe spills at once.
- Do not pour sand or sandy water down a sink; it clogs drains. Let it settle in the bucket and pour the clear water off outside.
- Pushpins for the drains are sharp; only the student assigned the drain kit handles them, and they go back in a closed box. Wash hands after the lab; no eating or drinking at the trays.

Teacher preparation and setup

1. The day before, premix the sand in sealed zip bags, 1,000 mL of dry play sand per bag, measured with a measuring jug: A = no water; B = 50 mL; C = 125 mL; D = 250 mL; E = add water slowly until a thin film just appears on the surface after mixing (usually 300-400 mL; write the amount on the bag). Knead each bag to mix and keep it sealed so it does not dry out.
2. Assign two levels per group so each level is tested by at least three groups. For eight groups: G1 A and C, G2 B and D, G3 C and E, G4 A and D, G5 B and E, G6 A and B, G7 C and D, G8 D and E.
3. Cut the shelf liner to fit each tray and put a tape line across the tray 20 cm from the upper end. The sand bed fills the upper 20 cm; the lower part is the runout zone.
4. Measure each tray's bottom length, from the pivot edge on the table to the raised edge under the ruler; flared roasting pans are shorter at the bottom than at the rim. If it is not 30 cm, make a new height column with height = tray length x sine of the angle, using the sine values printed on the recording sheet.
5. Poke the rain cups and check that 50 mL drains in roughly 20-40 seconds; aim for all cups within 10 seconds of each other.
6. Make the class chart: five rows (A-E) with space for each group's mean failure angle.

Investigation design

Independent variable Session 1: water added per 1,000 mL of sand (0, 50, 125 and 250 mL, and saturated). Session 2: the mitigation (none, cover and gutter, drains, or toe wall).

Dependent variable	Session 1: the slope angle at first crack and at failure. Session 2: the number of 50 mL rain doses before failure.
Controlled	Same washed play sand, 1,000 mL per bed; Same bed length (20 cm) and thickness (about 2.5 cm) and the same five pats; Same tray and liner, measured the same way; Same lifting rate of about 1 cm every 5 seconds; Same starting angle (30 degrees), rain cup height and dose size in session 2
Trials	Three trials per level per group; each level is tested by at least three groups, so the class has nine or more trials per level. One bare run and one mitigated run per group in session 2, pooled across the class.
Comparison	Class mean failure angle at each water level, and doses to failure for bare slopes against each mitigation.

Student procedure

1. Session 1. Each student writes a prediction for q1. Then put on goggles, lay the liner in the tray, and set the tray flat with its lower end butted against a heavy book so it pivots without sliding.
2. Open your first bag, knead it, and spread the sand in the upper 20 cm of the tray. Level it with a straightedge to about 2.5 cm thick and press it flat with five light pats of an open hand. Build every bed the same way.
3. Tilt test: the Reader holds the ruler upright at the upper end. The Lifter raises that end about 1 cm every 5 seconds as the Watcher counts. The Watcher calls 'crack' at the first crack or rolling grains and 'fail' when sand crosses the tape line by 2 cm. The Reader reads the height at each call.
4. The Recorder converts both heights to angles with the height table and records how the sand moved: grains rolling down the surface, a block sliding, a slump that bulges at the toe, or a flow like wet cement.
5. Lower the tray, scoop the sand back into the zone, rebuild the bed and repeat for three trials. Then do three trials with your second bag. Reseal each bag between trials.
6. Compute the mean failure angle for each of your levels, post both on the class chart, and copy the class means into the class table. Plot the class means on the graph and answer q2.
7. Session 2. Time how long 50 mL takes to drain from your rain cup and record it. Build a bed from a fresh bag of level B sand and prop the upper end on books at 15.0 cm, which is 30 degrees.
8. Rain test, bare slope: hold the rain cup about 10 cm above the upper half of the bed and pour in 50 mL. When it has drained, that is one dose. Keep dosing, up to 10 doses. Record the dose number at the first crack, the first water seeping out at the toe, and failure (sand crossing the tape line by 2 cm).
9. Rebuild with your second bag of level B sand and add your assigned mitigation. Cover and gutter: lay plastic wrap over the upper two-thirds of the bed and fold the index card into a gutter along its uphill edge that carries water off to the side. Drains: poke holes every centimeter along three straws and push them into the base of the bed from the toe, sloping slightly downhill, with their ends sticking out. Toe wall: tape eight craft sticks side by side and push them upright into the sand along the toe.
10. Repeat the rain test on the mitigated slope. Post both results on the class chart, copy the class results, clean up as directed, and answer q3 through q10 individually.

Expected observations

- Expected ranges, not yet tested in a classroom: dry sand (A) fails at about 30-35 degrees as grains avalanche down the surface; damp sand (B and C) stands much steeper, often 50 degrees or more, and fails by cracking or sliding as a block; wetter sand (D) fails lower; saturated sand (E) fails at the lowest angles, roughly 15-25 degrees, by slumping and flowing.
- First cracks usually appear a few degrees before failure in damp sand but almost none appear in dry sand, which fails grain by grain.
- In session 2, bare damp slopes at 30 degrees typically crack and then seep at the toe before failing after several doses; slopes with a cover often survive all 10 doses; drains and toe walls usually delay failure by a smaller amount.

Likely difficulties

- Uneven lifting. A jerk can trigger failure early. Have the Watcher count steadily and the Lifter use two hands; discard and repeat a trial that was jerked.
- Damp sand may hold even at 80-90 degrees. Record 'no failure by 90' and use 90 for the mean, noting it as a lower limit. Above 70 degrees the height barely changes, so readings there are rough.
- Saturated bags separate as water settles. Knead the bag right before each trial, and scoop some of the pooled water in with the sand so the bed stays saturated.
- Groups disagree about when 'fail' happened. The tape line rule (sand crosses it by 2 cm) settles most arguments; the Watcher's call is final.
- Session 2 rain cups drain at different rates. Count doses rather than seconds, and compare each group's mitigated run with its own bare run.

Structured debrief

1. Put the class graph on the board. Ask a group with level B and a group with level E to describe their failures side by side: a damp bed that stood steep and then cracked or slid as a block, against a saturated bed that slumped and flowed at a gentle angle. Then ask the class to state the pattern in one sentence: failure angle rises with a little water, then falls as the sand approaches saturation.
2. Draw two pairs of grains on the board: one pair with a thin curved water film joining them (damp), one pair floating in water that fills the gap (saturated). Explain that the film pulls the grains together, while the water filling every gap pushes outward and lightens the contact between grains, so friction drops; the water also makes the slope heavier. Reject 'lubrication' explicitly.
3. Compare the session 2 mitigations. The cover usually wins in the tray because it keeps nearly all the rain out; drains help by letting water escape at the toe; a toe wall props up the base but does not stop the slope from saturating. Ask which of these real places used which idea: plastic sheeting on Southern California slopes in storms, Portuguese Bend's dewatering wells, La Conchita's wall that was overtopped in 2005.
4. Close on forecasting: if failure depends on how much water is in the slope, then rain totals over days and soil moisture are the data to watch for most slopes, and short-burst rain intensity is the data to watch on burned slopes. That is how landslide and post-fire debris-flow alerts are built.

Recording sheet: what students fill in

Lab 1 recording sheet: Tilt, Soak, Slide

Your bed is a model hillside. The **failure angle** is the slope at which sand crosses the tape line by 2 cm. Find the angle from the height of the raised end with the table below. Water levels are mL of water mixed into 1,000 mL of dry sand: **A** 0, **B** 50, **C** 125, **D** 250, **E** saturated (amount written on the bag).

Height of the raised end for a 30 cm tray (height = 30 cm x sine of the angle)

Angle (degrees)	Sine of the angle	Height for a 30 cm tray (cm)
10	0.174	5.2
15	0.259	7.8
20	0.342	10.3
25	0.423	12.7
30	0.5	15.0
35	0.574	17.2
40	0.643	19.3
45	0.707	21.2
50	0.766	23.0
55	0.819	24.6
60	0.866	26.0
65	0.906	27.2
70	0.94	28.2
80	0.985	29.5
90	1.0	30.0

1. Prediction before testing: rank the five water levels A to E from the steepest failure angle to the gentlest. Explain your ranking in one or two sentences.

Answer: Any ranking with a reason earns credit. The ranking the data usually support is B or C steepest, then D, then A (dry), with E (saturated) gentlest. A common prediction is A steepest and E gentlest, falling steadily with water.

Why: The prediction is scored on whether it is stated clearly and justified, not on being right; the surprise of damp sand standing steeper drives q4 and q5.

- Ranks all five levels
- Gives a reason based on water and grains or on experience such as sandcastles

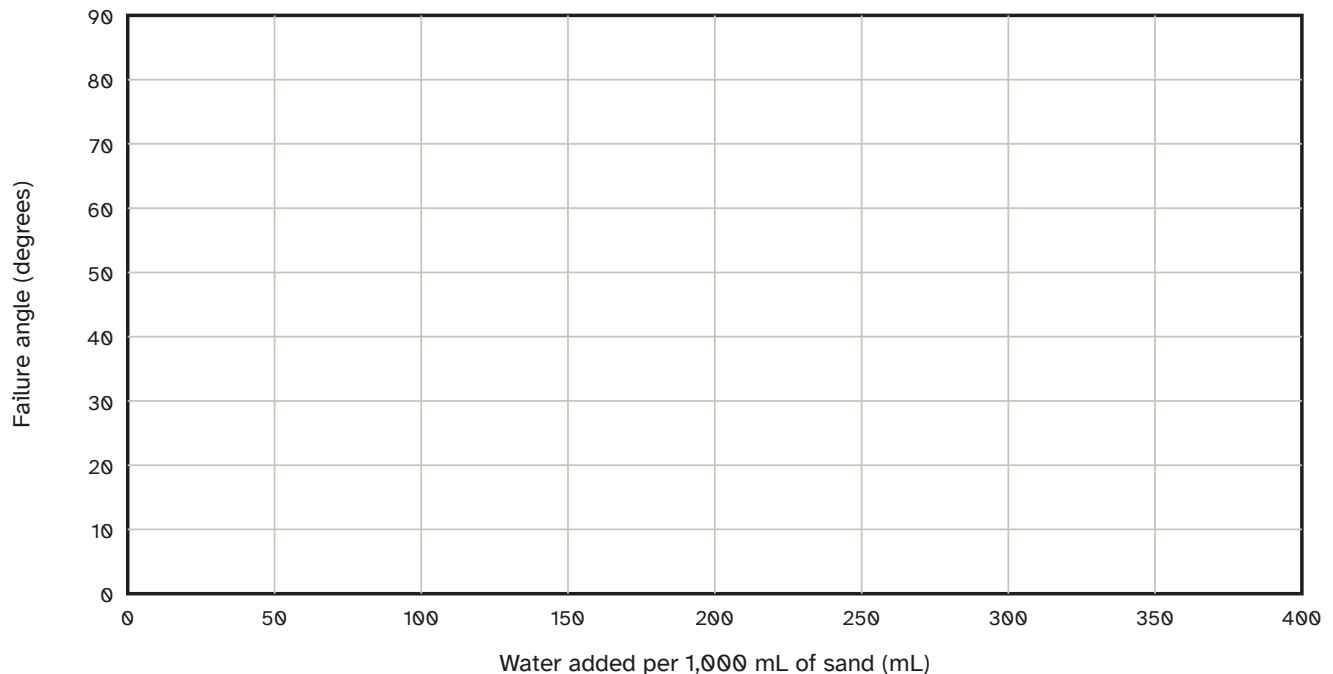
Session 1: our tilt trials

Water level	Trial	Height at first crack (cm)	Angle at first crack (degrees)	Height at failure (cm)	Angle at failure (degrees)	How the sand moved
	1					
	2					
	3					
	Mean					
	1					
	2					
	3					
	Mean					

Class results: mean failure angle at each water level

Level	Water per 1,000 mL sand (mL)	Group means (degrees)	Class mean (degrees)	Most common kind of movement
A	0			
B	50			
C	125			
D	250			
E	saturated: ____			

Class mean failure angle against water added



2. Describe what you saw at the moment of failure for your two levels. Which kind of real mass wasting did each one look most like: creep, a slide, a slump or a debris flow?

Answer: Dry sand: grains rolled and avalanched down the surface, like a small rock or sand fall. Damp sand: cracks opened, then a block slid or broke away, like a slide or slump. Saturated sand: the bed bulged at the toe and flowed like wet cement, like a debris flow or mudflow.

Why: Students match failure styles to the lesson's categories; the tray cannot show creep, which is too slow.

- Describes each of the group's two failures
- Matches each to a reasonable mass-wasting type

Session 2: rain on a 30-degree slope (one dose = 50 mL; rain cup drains in __ seconds)

Slope	Dose at first crack	Dose at first seep at toe	Dose at failure (or 'none by 10')	Rain at failure (mL)	What failed first
Bare slope					
With mitigation: _____					

Session 2: class results

Mitigation	Number of groups	Mean doses to failure, bare slopes	Mean doses to failure, mitigated slopes	Difference (doses)
Cover and gutter				
Drains				
Toe wall				

3. Compare your bare and mitigated slopes. How many more doses of rain did the mitigated slope take, and where did the water go in each case?

Answer: Group-specific. Example: the bare slope failed at dose 5 (250 mL); the covered slope had not failed after 10 doses, so it took at least 5 more. On the bare slope the rain soaked in and collected at the toe until it seeped out and the toe slumped; on the covered slope the water ran onto the plastic and off through the gutter, so the sand stayed damp.

Why: The answer must give the difference in doses and trace the water's path in both runs.

- States the difference in doses (or 'at least' if no failure)
- Describes where the water went on each slope

Analysis questions: answer key

4. Describe the pattern in the class graph. At which water level was the failure angle highest, and at which was it lowest? Is the pattern a straight line? Use numbers from the class table.

Answer: Class-specific; expected pattern: the failure angle rose from about 30-35 degrees for dry sand (A) to its highest, often 50 degrees or more, at a little water (B or C), then fell to its lowest, about 15-25 degrees, for saturated sand (E). It is not a straight line: it rises, peaks and falls.

Why: The key idea is the non-linear pattern; credit any class data correctly described.

- Names the highest and lowest levels with numbers
- States that the relationship rises then falls rather than following a straight line

5. Explain the pattern using what happens between sand grains. Why did damp sand stand steeper than dry sand, and why did saturated sand fail at the gentlest angle?

Answer: In damp sand, thin films of water form curved bridges between grains, and the water's surface tension pulls the grains together, so the sand holds a steeper slope; this is why damp sand makes good castles. As more water is added the films merge and their pull fades. In saturated sand, water fills every gap. Its pressure pushes outward on the grains, so they press on each other less and the friction between them drops; the water also adds weight to the slope. Less grip and more weight mean the slope fails at a gentle angle.

Why: This is the core mechanism. Full credit needs both effects of water and an explicit rejection of, or alternative to, the lubrication idea.

- Explains that water films pull damp grains together
- Explains that water filling the gaps lightens grain contact and lowers friction
- Mentions the added weight of water
- Does not rely on 'water lubricates'

6. Use your class means for level A (dry) and level E (saturated); if your class data are incomplete, use A = 34 degrees and E = 18 degrees. By how many degrees did saturation lower the failure angle? What percent of the dry failure angle is the saturated failure angle? Show your work.

Answer: With A = 34 and E = 18: difference = $34 - 18 = 16$ degrees. Percent = $18 / 34 \times 100 =$ about 53 percent. The saturated sand failed at roughly half the dry angle.

Why: Students subtract and then divide. With class data, check the arithmetic on the student's own numbers.

Also acceptable: Accept class values computed correctly; accept 52.9 percent or 'about half'.

7. Which mitigation delayed failure the most in the class results? Explain how it works in terms of water, and name one problem it would have on a real hillside.

Answer: Expected: the cover and gutter, because it keeps rain from soaking into the slope at all, so the sand never approaches saturation. Drains help less: water still soaks in but some escapes through the straws, keeping the toe drier. The toe wall props the base but the slope still saturates. Problems on a real hillside: plastic covers tear, blow off and only protect for one storm and can send runoff somewhere else; drains clog and need upkeep; walls can be overtopped, as at La Conchita in 2005.

Why: Students should tie each mitigation to the water mechanism and recognize real limits.

- Names the mitigation with the largest difference in class data
- Explains its effect on water in the slope
- Gives one realistic problem

8. The La Conchita bluff is about 180 m high with slopes of about 35 degrees, and its 2005 slide came at the end of about 15 days of heavy rain, not after the first storm. Use your session 1 and session 2 results to explain why failure came at the end of the wet spell.

Answer: A 35-degree slope is gentle enough to stand when the soil is merely damp, as damp beds in the tray held well above 30 degrees. Each day of rain added water until the slope neared saturation, as the bare slopes in session 2 needed several doses before seeping and failing. Near saturation the failure angle drops toward 20 degrees or lower, below the bluff's 35 degrees, so it failed at the end of the wet spell rather than after the first storm.

Why: Students must combine the two sessions: water accumulates over time, and the failure angle drops as it does.

- Uses the idea that water builds up over many days
- Uses the class result that saturated sand fails below 35 degrees
- Explains why the first storm was not enough

9. Name three ways the tray is different from a real hillside, and say for each one whether it would make a real slope fail more easily or less easily than the model.

Answer: Any three, for example: real slopes are made of layered soil, clay and broken rock (clay layers and old slip surfaces make failure easier); real slopes have roots holding them (harder, unless burned); real slopes get groundwater flowing in from uphill for days (easier); real slopes are far longer and heavier (usually easier, since weight adds up); real slopes can be shaken by earthquakes (easier); the model's sand is uniform and freshly packed (either way).

Why: Credit any three plausible differences with a reasoned direction.

- Three distinct differences
- A direction (more or less likely to fail) with a reason for each

- 10.** You are setting up a landslide watch for a steep slope above a road that burned last summer. Which two measurements would you monitor, and what reading would make you warn the road crew? Use evidence from this lab and from the lesson.

Answer: Monitor rain intensity over short periods, about 15 minutes, because on burned slopes a short burst can set off debris flows (Montecito 2018), and soil moisture or rain totals over several days, because the tray failed as it neared saturation. Warn the crew when forecast or measured 15-minute rain intensity exceeds the threshold set for that burned slope, or when the soil sensor shows the slope near saturation. Also watch for cracks or tilting at the top of the slope.

Why: Students should pick measurable quantities tied to the mechanism and state a threshold-style rule.

- Two measurable quantities linked to water in the slope
- A clear trigger or threshold
- Evidence from the lab or the lesson

Individual evidence of learning

Each student submits the completed recording sheet, the class graph and answers to q1 through q10. The graph with q4 and q5 is the evidence for explaining how water content changes slope stability; q6 is the calculation; q7, q8 and q10 show the student using the model's data to judge mitigation and to choose what to monitor for a real slope.

Assessment criteria

Criterion	Proficient looks like
Measurement	Three trials per level with heights to the nearest 0.5 cm, correctly converted to angles, and a mean for each level.
Pattern from data	Describes the rise-then-fall pattern with class numbers, naming the highest and lowest levels (q4).
Grain-scale explanation	Explains that thin water films pull grains together while water filling the gaps lightens grain contact and adds weight, and rejects 'lubrication' (q5).
Calculation	Computes the difference and the percent correctly with work shown (q6).
Using the model for real decisions	Connects the results to La Conchita's long wet spell and names sensible measurements and a threshold for a burned-slope watch (q8, q10), with at least one model limitation (q9).

Accessibility adaptations

- Provide the height table with 5-degree rows highlighted and a calculator for means; let a student with dyscalculia use a pre-made height-to-angle strip taped to the ruler.
- Students with limited strength or fine-motor control can take the Watcher or Recorder role; a partner builds the bed while they direct it.
- For low vision, tape a high-contrast ruler with large centimeter marks upright beside the tray, and have the Reader call every reading aloud.

- Students who cannot handle sand (skin conditions, sensory needs) can run the timing, recording and graphing, and observe with goggles from a step back.
- Accept a labeled photo series of a failure, with spoken commentary recorded on a device, in place of the written description for q2.

Low-cost alternative

If trays or sand are short, run session 1 as a demonstration at the front with two trays (dry and saturated) while groups predict, record and graph, and use clean playground sand dried in the sun. A cardboard box lid lined with a plastic grocery bag can replace the tray for dry and damp levels. Session 2 can use one tray per two groups, each group running one bare and one mitigated slope in turn.

Model limitations

This activity has not been physically tested by the authors; the angles in the key are expected ranges based on how sand behaves, and classes should trust their own data. The tray is a model: real hillsides are hundreds of meters long, made of layered soil, clay and broken rock rather than uniform sand, held together by roots, and fed by groundwater flowing in from uphill over days or weeks. Real slopes often fail along a buried weak layer, which the liner only roughly imitates. Clay-rich soils behave differently from sand, and the model cannot show slow creep or the effect of earthquake shaking. The 50 mL doses fall far faster, relative to the bed's size, than real rain.

Teacher notes

The tilt angles depend on the sand, the liner and the packing, so judge students on correct measurement, clear patterns and explanations rather than matching the expected ranges. If a level B or C bed will not fail before 90 degrees, record 90 as a lower limit; the pattern still holds. Keep q5 central in the debrief: it is the explanation students will reuse for every slope in the chapter. For q6 accept class data. The session 2 cover often 'wins' by a lot; push students in q7 to discuss why real slopes cannot be wrapped in plastic for years.