

Build a Better Filter: Can Sand and Gravel Do a Watershed's Job?

Investigation question: Using only gravel, sand, cotton balls and coffee filters and a \$10 classroom budget, how can a team design a filter that makes muddy runoff clear enough and fast enough, and how does the best filter compare with the filtering a forested watershed does for free?

Engineering design challenge

Groups of 4

2 sessions

Setup 10 · Activity 90 · Cleanup 10 min

MS-ETS1-3 · practice

MS-ETS1-2 · practice

MS-LS2-5 · practice

MS-ESS3-3 · supports

Name _____

Group _____

Date _____

Your role today

- ☐ **Builder:** Assembles the layers from the design sketch, levels each layer gently, and pre-wets the filter.
- ☐ **Tester:** Stirs and measures the runoff, pours it in one steady pour, runs the timer and measures the volume collected at 3 minutes.
- ☐ **Rater:** Pours 100 mL of the collected water into a clear cup, compares it with the reference cups on the X card, and reports the clarity rating.
- ☐ **Accountant:** Checks the design against the budget before materials are collected, records all results, marks each criterion met or missed, and posts to the class table.

Safety

- The filtered water is not safe to drink and must never be tasted, even when it looks clear: sand, gravel and cotton do not remove germs or dissolved chemicals.
- Soil can carry bacteria and fungi. Use bagged topsoil, keep hands away from faces, cover cuts or wear gloves, and wash hands with soap after each session.
- Cut plastic edges are sharp. Only the teacher cuts bottles, and every edge is taped before students handle it.
- Spilled water and sand make floors slippery; work over trays and wipe spills at once.
- Pour used water, sand and gravel into the class bucket, never into the sink, where sand and soil can clog the drain; empty the bucket outdoors onto soil.
- Students with soil, mold or dust allergies wear gloves and can take the Rater or Accountant role.

Procedure

1. Session 1. Read the challenge, criteria, constraints and price list on the recording sheet. Answer q1: which criterion do you expect to be hardest to meet, and why?
2. Sketch your Round 1 design in the drawing box: every layer from top to bottom with its amount and cost, and the total. The Accountant checks that the total is \$10 or less before anyone collects materials.

3. Build. Set the bottle top upside down in the bottom half. Put any coffee filter or cotton plug in first, at the neck, then add the layers in your planned order, leveling each one gently without pressing it down hard.
4. Pre-wet the filter by pouring 50 mL of tap water through it; let it drain and empty the collector. Dry sand soaks up water, which would make the volume test unfair.
5. Test. Stir the runoff, measure 250 mL and pour it into the filter in one steady pour, starting the timer as you begin. At 3 minutes lift the filter out of the collector and measure the volume collected.
6. Rate. Pour 100 mL of the collected water into a clear cup and compare it with reference cups R0-R5 on the X card. Record the rating, volume, cost and whether each criterion was met, then post your design features and results on the class table.
7. Session 2. Study the class table and answer q2 and q3: which features appear in the clearest designs, which in the fastest, and is there a trade-off?
8. Redesign. Change at least one feature, borrowing from another team's design where the data support it. Add Round 2 to the drawing box with costs and a one-line reason for each change.
9. Rebuild with fresh or rinsed sand and gravel, pre-wet, and test again exactly as in Round 1. Record and post the results and answer q4.
10. Clog test, if time allows: without changing anything, pour a second 250 mL of runoff through the Round 2 filter and measure the volume at 3 minutes and the rating again.
11. Clean up: empty sand, gravel and water into the class bucket, rinse the cups, wipe trays and wash hands. Answer the analysis questions individually.

Record your observations

Lab 2 recording sheet: Build a Better Filter

A town's creek turns muddy after storms. Your team must design a filter that cleans a sample of the runoff.

Criteria: the collected water has a clarity rating of **at least 3** (stretch goal: 4), and **at least 150 mL** comes through within 3 minutes of pouring 250 mL. **Constraints:** total cost **no more than \$10** in classroom money; only gravel, sand, cotton balls and coffee filters; every layer fits inside the top half of the bottle.

Never drink or taste the water, however clear it looks.

Price list (classroom money)

Material	Unit	Price
Gravel	100 mL scoop	\$1.00
Sand	100 mL scoop	\$2.00
Cotton ball	1 ball	\$0.50
Coffee filter	1 filter	\$1.50

Clarity scale

Rating	Most similar reference cup	Share of the runoff's cloudiness left (about)
0	R0 (runoff)	all of it
1	R1	1/2
2	R2	1/4
3	R3	1/8
4	R4	1/16
5	R5 (tap water)	none visible

1. Before you build: which criterion or constraint do you expect to be hardest to meet, and why?

-  Draw your filter from the side, Round 1 on the left and Round 2 on the right. Label every layer from top to bottom with its amount (mL or count) and cost, and write each total. Under Round 2, give a one-line reason for each change.

Our test results

Test	Layers, top to bottom (amounts)	Cost (\$)	Volume in 3 min (mL)	Clarity rating (0-5)	Criteria met? (clarity / volume / cost)
Round 1					
Round 2					
Clog test (second pour, Round 2 filter)					

Class results

Team	Key features (layer order, sand amount, plug)	Round	Rating	Volume (mL)	Cost (\$)

2. Look at the class table. What features do the designs with the highest clarity ratings share? What features do the fastest designs share?

3. Is there a trade-off between clarity and speed? Use two teams' numbers as evidence.

4. Describe your Round 2 change and the reason for it. Did the Round 2 results confirm your reasoning? Give the numbers.

Analysis questions

5. Use the clarity scale. About what percent of the runoff's cloudiness did your best filter remove? (A rating of 3 leaves about $\frac{1}{8}$, so it removed about $\frac{7}{8}$.) Show your calculation.

- 6.** What happened to the flow and the clarity on the clog test, and why? What would a real treatment plant have to do about clogging, and what does that cost?

- 7.** Name the best feature of two different teams' designs and explain how combining them could beat both. Use numbers from the class table.

- 8.** Your best water may look clear. Name two kinds of things that could still be in it, and explain why sand, gravel and cotton cannot remove them.

- 9.** Compare your filter with a forested watershed like the ones that supply New York City. Give one way they work alike and two ways the watershed is different (think about cost, upkeep and what else it provides). Then explain why New York still disinfects its water.

- 10.** Suppose a filter like yours cost \$9 and cleaned 0.5 L of runoff before it clogged and had to be replaced. (a) What did it cost per liter? (b) A town uses 10 million liters of water a day. At that cost per liter, what would one day of water cost? (c) Real plants wash and reuse their sand. Why does that matter for this comparison?

- 11.** A housing development is planned beside the creek that feeds a town's reservoir. During construction, bare soil will wash into the creek in storms. Propose one way to monitor the impact and one way to reduce it, and explain how each connects to this lab.
