

HANDS-ON STEM LAB · ENVIRONMENTAL SCIENCE & CHEMISTRY

Is Our Water Safe?

Investigating CO₂ Leaks in Groundwater

Students become citizen scientists!

Students simulate how injected carbon dioxide interacts with underground aquifers and learn how to help protect their community's groundwater.

2 class periods

Grades 9–12

Groundwater aquifers

Real monitoring techniques

WHY THIS LAB MATTERS

Carbon Storage & Groundwater Safety

Carbon capture and storage (CCS) is a key strategy in the reducing greenhouse gas emissions. By capturing CO₂ from industrial sources and storing it deep underground — often in the same types of formations where we once extracted fossil fuels — we can reduce the amount entering the atmosphere. This process is increasingly being implemented across the Gulf Coast and other regions.

To ensure this technology is safe for people and the environment, the U.S. Environmental Protection Agency (EPA) regulates these storage activities through Class VI of the Underground Injection Control (UIC) program. These rules are specifically designed to protect underground sources of drinking water, defined as water <10,000 TDS, and include requirements to monitor groundwater near injection sites. But communities near these projects have important questions: **What happens if safeguards fail or someone makes a mistake, causing CO₂ to leak into drinking water?**

This lab lets students find out for themselves. By putting accessible, real-world science directly into the hands of high school students, it empowers them and their communities to better understand the environmental challenges that affect them. Students will build small-scale aquifer models, inject CO₂, and track chemical changes in the water using the same techniques that environmental scientists use in the field—transforming them from learners into investigators

✓ LAB TIMING

This lab is designed for **two 50-minute class periods** to ensure adequate data collection. Day 1 covers field-style measurements (pH, conductivity). Day 2 covers lab-style measurements (calcium, alkalinity). The aquifer chambers can be assembled the day before to ease time constraints. If you are on a block schedule, the lab can be completed in one full class period with minor adjustments.

What students will learn

- Understand how CO₂ naturally fits into the carbon cycle, particularly in soil and groundwater systems, and explore its role in processes like respiration, dissolution, and mineral interactions — as well as its potential environmental impacts
- Discuss the role of CCS in the context of greenhouse gas sources and sinks
- Explore how groundwater is monitored to detect possible CO₂ leakage into drinking water aquifers, using real-world techniques and indicators
- Apply basic chemistry concepts to understand how CO₂ interacts with groundwater through
 - acid-base reactions, pH buffering and changes, alkalinity, water hardness, and mineral
 - dissolution and reactivity
- Practice groundwater sampling methods, including collection, measurement, and analysis of water quality parameters
- Get a better understanding of the potential environmental impacts of CO₂ leakage on aquifers

BACKGROUND READING

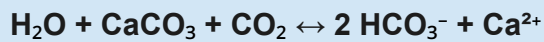
The Science Behind the Experiment

How does CO₂ get into groundwater?

CO₂ is not just an industrial byproduct — it is a natural and essential part of Earth's carbon cycle. In fact, CO₂ is constantly produced in the shallow subsurface, especially in soils when plant roots and soil microbes respire. As they break down organic matter, CO₂ builds up in the air spaces (pores) between soil grains, generating far more CO₂ underground than is typically found in the atmosphere above.

When it rains, water moves downward through the soil (infiltration). As rainwater percolates through these CO₂-rich pores, it dissolves the gas into solution — governed by **Henry's Law**, which says the amount of gas that dissolves into a liquid is directly proportional to its partial pressure and solubility at a given temperature. Once CO₂ dissolves, it forms **carbonic acid (H₂CO₃)**:

KEY REACTION — CARBONATE SYSTEM MASTER EQUATION



Water + Limestone + Carbon dioxide $\leftrightarrow$ Bicarbonate + Calcium ions

More CO₂ pushes the reaction forward, dissolving limestone. If CO₂ decreases, the reaction reverses and minerals may re-form. This is **Le Châtelier's Principle** in action — when a system at equilibrium is disturbed, it shifts to reduce that disturbance.

Why does rock type matter?

The type of rock in the aquifer plays a major role in determining how groundwater chemistry changes when CO₂ is introduced. These reactions form the basis for interpreting monitoring results in real CO₂ storage projects. See a breakdown of the characteristics below:

Carbonate Aquifer

Limestone (CaCO₃) · White rocks

- CO₂ reacts quickly with limestone
- Limestone **dissolves**, releasing Ca²⁺ and HCO₃⁻ into the water
- This consumes H⁺ ions, **neutralizing acidity — pH barely drops**
- Water hardness, alkalinity, and total dissolved solids all increase
- Acts as **nature's buffer**

Silicate Aquifer

Quartz / Feldspar · Brown rocks

- Silicate minerals dissolve much **more slowly**
- Buffering capacity is low — CO₂ acid is not neutralized quickly
- pH drops **more noticeably**
- Calcium and alkalinity show minimal change — rocks aren't dissolving quickly
- Acts as a **poor buffer**

Based on the characteristics listed above, we expect to see the following responses from each water monitoring parameter once the aquifers are introduced to carbon dioxide.

Parameter	Carbonate aquifer	Silicate aquifer
pH change	Small drop (buffered by rock)	Larger drop (unbuffered)
Calcium (Ca ²⁺)	Increases as limestone dissolves	Minimal change
Alkalinity (HCO ₃ ⁻)	Increases	Minimal change
Conductivity (TDS)	Increases (more dissolved ions)	Small or no increase

Materials

SAFETY AND STANDARDS

Wear nitrile gloves and eye protection throughout this lab. Dispose of all chemical waste according to proper guidelines. Rinse containers and beakers with distilled water between samples when testing for fluid parameters. CO₂ under pressure can release quickly — always turn the regulator knob fully *off* (-) before inserting a cartridge. Test the assembled system by briefly opening the regulator and listening for hissing that could indicate a leak.



CHAMBERS & CONTAINERS

- 2 — 32 oz mason jars or standard 1000 mL beakers
- 2 — 50 mL beakers (one each for Silicate / Carbonate)
- 1 — 1000 mL beaker (waste disposal)
- Distilled water



ROCK MATERIALS

- Silicate rock pebbles (brown)
- Limestone / carbonate rock pebbles (white)



CO₂ INJECTION

- 2 CO₂ cartridges (20 g each)
- CO₂ regulator with knob
- Aquarium bubbler + ¼" clear tubing
- Quick Connect adapter ⅜" to ¼"
- 2–3 inch piece of ⅜" clear tubing
- 2 binder clips (optional)



MEASUREMENT TOOLS

- pH sensor
- Conductivity sensor (µS/cm)
- Calcium hardness test kit
- Alkalinity test kit
- 2 large syringes + 12 filters (1 filter per sample)
- 12 labeled sample tubes with lids (enough for 3 time steps for both aquariums)



SAFETY & MISC

- Nitrile gloves
- Safety goggles
- Kimtech wipes
- Sharpie marker
- Data sheets and method to plot results (excel, google sheets, printed plots, etc)

✓ DETAILED SUPPLY LIST

A *Detailed Project Supply List* with direct purchasing links, current prices, and quantities is available in the Resources section. All materials have been selected for availability, and ease of ordering. Many are reusable across multiple classes or experiments, helping reduce cost over time.

Assembling the aquifer chambers

1. Fix a bubble stone to one end of the aquarium tubing and place it at the bottom of the jar.
2. Fill one jar completely **white carbonate rocks**; fill the other with **brown silicate rocks**. The more full a jar, the more reactivity you will observe; however, you may experience more difficulty pulling water samples. At minimum, at least 60-70% full is recommended.
3. Carefully add distilled water until there's just enough room at the top where the water will not overflow once the CO₂ bubbles through. Make sure the tubing stays submerged at the bottom. Each chamber holds approximately 1 liter total (450 mL of water and 550 mL of rock — about 45% porosity), allowing roughly 10 samples per chamber if 30-40 mL is collected per sample.
4. Secure free tubing ends upright with a binder clip attached to the top of the jar to stop flow between samples.
5. *Tip: If time allows, letting the system soak overnight before the experiment improves the quality of the baseline reading.*

DAY 1 & DAY 2

Step-by-Step Procedure

Setting the Scene

Look at the two chambers. In this model, the container represents the groundwater formation, the rocks are the geologic composition, and the tubing connected to the bottom of the chamber are our wells. In this experiment, this well is both our injection and monitoring well. This lab will simulate a simplified version of a real-world "huff and puff" test—a technique used by researchers to study how CO₂ behaves underground. In this method, CO₂ is injected into an aquifer, allowed to react with the surrounding water and minerals over time, and then the water is extracted and analyzed. By observing the resulting geochemical changes, scientists can determine what chemical processes occurred during the CO₂ exposure.



BEFORE YOU BEGIN — MAKE A PREDICTION!

Before beginning, ask students to make predictions about how each aquifer type will respond to the CO₂ injection: *"How do you think pH, calcium concentration, and alkalinity will change in each aquifer type once CO₂ is added?"* Students should write down their hypotheses using key terms like **equilibrium shift**, **buffering**, **mineral dissolution**, and **ion formation** (H⁺, HCO₃⁻, Ca²⁺).



Lab Overview Video

Watch a walk through of the full experiment for step-by-step guidance

[Watch Video](#)



Procedure Quick Guide (PDF)

A condensed one-page reference for running the lab

[Download PDF](#)

Day 1 — Field Measurements

1

Prepare the aquifer models

Construct the two aquifer models complete with monitoring and injection well as described in the Setup section above.

2

Sensor setup & calibration

Calibrate the pH and conductivity sensors following the kit instructions before taking any readings. Set conductivity units to μS/cm.

3

Prepare the sampling station

Label 12 sample tubes: C1–C6 for carbonate, S1–S6 for silicate. Label both 50 mL beakers and both syringes to match their chamber. Assign student roles: sampler, recorder, timer, tester, filter technician. Rotate when possible so students get a chance to try different things.

4

Establish baseline (S1 & C1)

Before injecting CO₂, record the initial time of your first sample. Draw 30–40 mL from each chamber through the tubing. This may require a syringe to create enough suction. Pour into a 50 mL beaker. Take the baseline pH reading: insert the sensor all the way to the bottom and swirl slowly until the reading stabilizes, then record. Wipe the sensor with a Kimtech wipe. Take the conductivity reading. Repeat for the other chamber. Record pH and conductivity. Alkalinity and calcium are tested next from the filtered sample.

5 Filter & store baseline samples

Attach a filter to the syringe. Remove the plunger, pour in the sample from the 50 mL beaker, reinsert the plunger. Point tip up, remove filter, expel air, reattach filter. Push the plunger slowly to filter water into the clean, labeled sample tube. Seal and set aside for Day 2 lab-style testing. Use a fresh filter for each sample and dry all beakers, syringes, and tools between uses after rinsing with distilled water to minimize cross-contamination.

6 Inject CO₂ — simulate the "huff and puff" test

Begin by inserting the CO₂ cartridge securely into the regulator. Ensure the regulator knob is turned fully off before puncturing the cartridge. Connect the aquarium tubing to the CO₂ regulator with an adapter. Ensure all connections are tight (test by briefly opening and listening for hissing). Slowly open the regulator knob — bubbles will appear as CO₂ flows. Allow the entire 20 g cartridge to empty into the chamber. *Note: Each chamber must be injected with CO₂.*

7 Monitor changes — sample every 10–15 minutes for 1 hour

Once CO₂ injection is complete, begin taking water samples from each chamber every 10–15 minutes, depending on time constraints. Samples early on (within the first 30 minutes) helps capture the most dramatic changes — but changes will continue to happen for a few days. For each sample: collect 30–40 mL from each chamber into its labeled beaker, immediately measure pH and conductivity, wipe sensors between samples, then filter and store in a labeled tube for Day 2.

Note: If conducting the experiment in one day, other lab partners can run calcium and alkalinity tests while the field samples are pulled from the chamber.

Day 2 — Lab Measurements

8 Run calcium hardness test

Using the stored and filtered samples from Day 1, perform the calcium test following the instructions provided with the test kit for each sample (also detailed in the quick guide linked above. This is specific to the Salifert Calcium Kit). Record the result in mg/L on the data sheet.

9 Run alkalinity test

Perform the alkalinity test following the instructions provided with the test kit for each stored sample (also detailed in the quick guide linked above. This is specific to the Salifert Alkalinity Kit). Record the result in meq/L on the data sheet.

10 Graph your results & analyze

Plot pH, calcium, and alkalinity on the y-axis against time on the x-axis — one line for the carbonate system, one for the silicate system, on each graph. Compare how the two systems responded. Look for patterns and trends in the data that support or challenge your initial hypothesis.

EXAMPLE OF STUDENT ROLES

Sampler — draws water from chambers | **Measurer** — operates sensors | **Recorder** — fills in data table | **Timer** — tracks 10–15 min intervals | **Filter technician** — filters and stores samples. Not everyone will get to do every job, but rotate when you can so students experience each role. Encourage them to watch and help each other to stay involved and learn from the whole process.

RECORDING RESULTS

Data Collection Table

Use the table below (or print it) to record measurements for each time point. Take baseline readings before CO₂ injection, then measure every 10–15 minutes. Keep in mind that results may vary depending on factors such as how long the chambers sit before the experiment begins, rock composition, and temperature.

Sample	Aquifer	Time	pH	Conductivity (μ S/cm)	Calcium (mg/L)	Alkalinity (meq/L)	Notes
C1	Carbonate						
S1	Silicate						
C2	Carbonate						
S2	Silicate						
C3	Carbonate						
S3	Silicate						
C4	Carbonate						
S4	Silicate						
C5	Carbonate						
S5	Silicate						
C6	Carbonate						
S6	Silicate						

C = Carbonate aquifer | S = Silicate aquifer | Calcium and alkalinity columns are completed on filtered samples, make sure labels are correct.

Discussion Questions

After graphing results, use these questions to guide a reflective, student-centered discussion that encourages critical thinking:

What are the key differences between carbonate-rich and silicate aquifers when CO_2 is introduced? Which parameters changed the most in each?

How does Le Châtelier's Principle help us predict changes in groundwater chemistry? Which direction did the equilibrium shift when CO_2 was added?

Why did calcium and alkalinity change in the carbonate aquifer but not the silicate aquifer? What does this tell us about mineral dissolution and reactivity?

In what ways does understanding groundwater chemistry enhance CO_2 monitoring efforts? If you were a scientist monitoring a real storage site, which parameters would you watch most closely?

How does the interaction of CO_2 with groundwater illustrate the broader carbon cycle?

What are the potential risks and benefits of storing CO_2 underground in terms of climate change mitigation? Based on your results, do small CO_2 leaks pose a major risk to drinking water?

How does the natural behavior of carbonate rocks — buffering acid — factor into the design of CCS safety monitoring programs?

What do these results tell us about CO₂ storage safety?

Small leaks are detectable

Even small CO₂ additions cause noticeable changes in pH, calcium, and alkalinity — especially in carbonate systems. These changes serve as clear geochemical fingerprints that can be used to detect and track leaks early.

Groundwater reacts predictably

Carbonate aquifers buffer acid quickly, converting CO₂ to harmless dissolved forms like bicarbonate. Silicate aquifers respond more slowly but eventually stabilize. Aquifers are not passive — they naturally reduce the impact of CO₂ leaks.

Risks are limited & local

Most changes are chemical — lower pH, higher calcium and alkalinity — but within safe ranges at classroom scale. Most changes are not directly toxic.

Monitoring works

The same parameters measured here — pH, conductivity, calcium, alkalinity — are used in real EPA Class VI groundwater monitoring programs. Leaks are not invisible; they can be reliably detected before spreading or causing harm.

Visit our website

Resources

All materials are available online at put-it-back.org.

List of available resources include:



Teacher Manual — AP Environmental Science

Full facilitation guide including objectives, background, setup instructions, discussion prompts, and standards alignment.



Teacher Manual — Chemistry

Full facilitation guide with chemistry-specific context, pre-lab reading, step-by-step instructions, and TEKS alignment.



Lab Overview Video

A step-by-step video walk through of the experiment, including setup, CO₂ injection, sampling, and measurement techniques.



Student Lab Manual

Student-facing handout with pre-lab reading, safety notes, procedure, data table, and analysis questions.



Detailed Supply List

Itemized list with purchasing links, current prices, and quantities needed for one class.



Procedure Quick Guide

Condensed one-page reference card for students to keep at the bench during the experiment.