What Makes a Slope Stable or Unstable?

Slopes fail when driving forces exceed resisting forces.

1 THE BASIC IDEA

Slope stability depends on the balance between forces pulling material downhill and forces holding it in place.

2 STABLE SLOPE

Resisting forces balance or exceed driving forces.

DRIVING FORCES | **RESISTING FORCES**

Resisting ≥ driving = stable

3 SLOPE NEAR FAILURE

Driving forces exceed resisting forces.

DRIVING FORCES | **RESISTING FORCES**

Driving > resisting = instability / potential failure

4 WHAT AFFECTS STABILITY?

GRAVITY
The constant pull of gravity drives movement downslope.

SLOPE ANGLE
Steeper slopes increase driving forces.

SOIL/ROCK STRENGTH
Stronger materials and good structure resist movement.

VEGETATION ROOTS
Roots bind soil together and add strength.

WATER
Water infiltration raises pore pressure and reduces strength.

5 THE BALANCE THAT MATTERS

When resisting forces are greater than or equal to driving forces, the slope is **stable**.

When driving forces exceed resisting forces, instability occurs and **failure** can happen.

POLICY TAKEAWAY

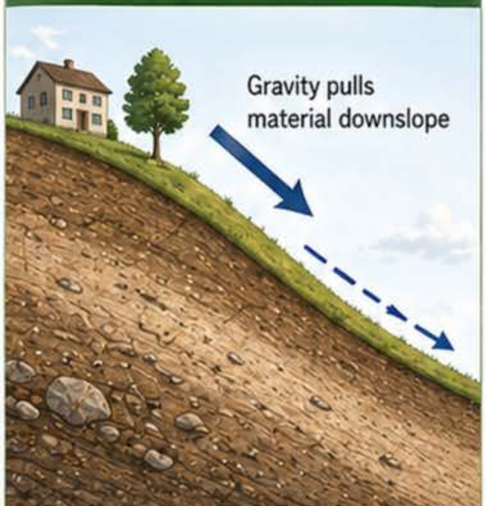
Slope stability is not just about steepness. Drainage, grading, vegetation, and ground conditions all affect whether land can safely support development or infrastructure.

The Role of Gravity, Slope Angle, and Material Strength

Steeper slopes and weaker materials are more likely to move.

1 HOW GRAVITY, SLOPE ANGLE, AND MATERIAL STRENGTH WORK TOGETHER

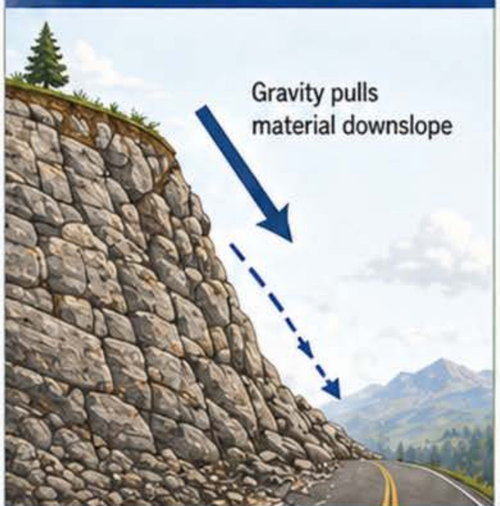
GENTLE SLOPE



More likely to stay stable

Gentle slope = lower driving force

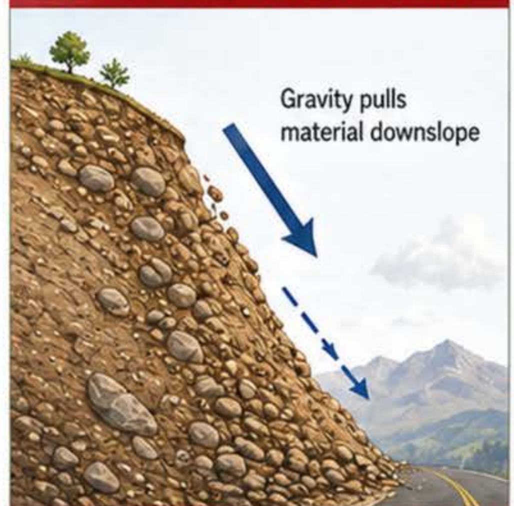
STEEP SLOPE + STRONGER MATERIAL



More likely to stay stable

Steep slope, but stronger material resists movement

STEEP SLOPE + WEAKER MATERIAL



Higher chance of movement

Steep slope with weak, loose, or weathered material = higher risk

Slope angle matters — **Material strength matters**

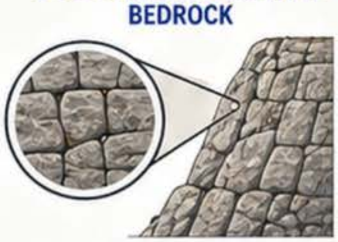
2 WHY MATERIAL MATTERS

WEAK, LOOSE, OR WEATHERED MATERIAL

Particles are loose and poorly connected.

Easier to deform or slide.

STRONG, WELL-CEMENTED BEDROCK



Particles are tightly locked together.

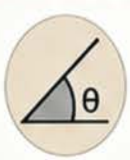
Resists deformation and movement.

3 THE BIG PICTURE

4 KEY FACTORS THAT CONTROL SLOPE STABILITY

GRAVITY

Always acting downward, it drives materials downslope.



SLOPE ANGLE

Steeper slopes create greater driving forces on the material.

MATERIAL STRENGTH

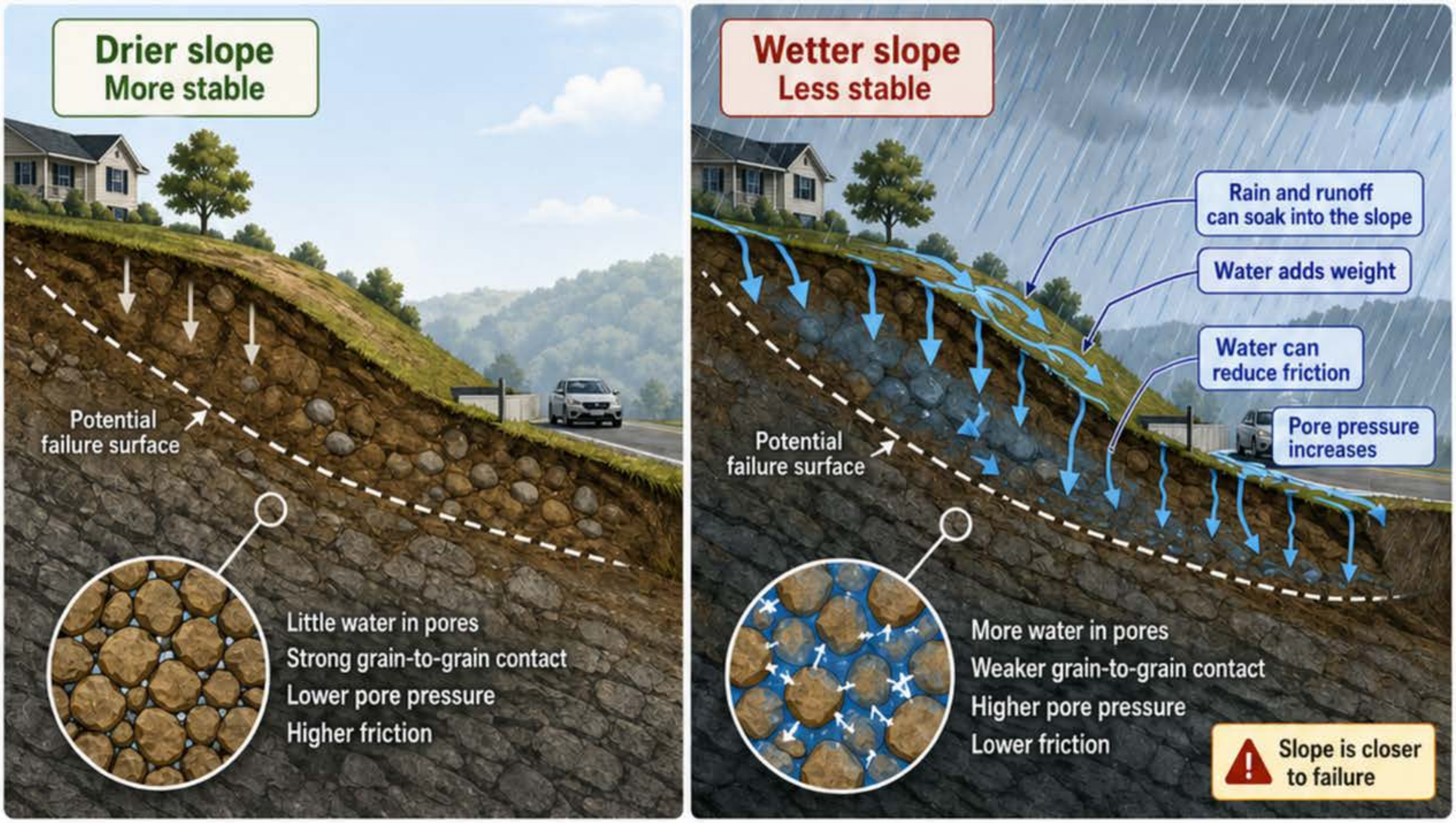
Stronger, well-cemented materials resist movement; weaker materials do not.

POLICY TAKEAWAY

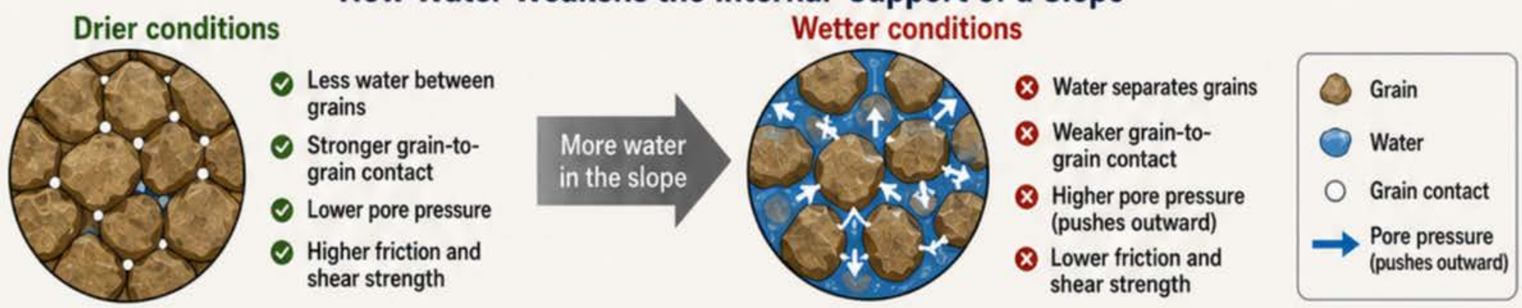
Policy takeaway: Steeper slopes and weaker earth materials usually need more careful design, review, and hazard screening. These factors matter for hillside development, road cuts, and land-use planning.

Why Water Is Often the Trigger for Slope Failure

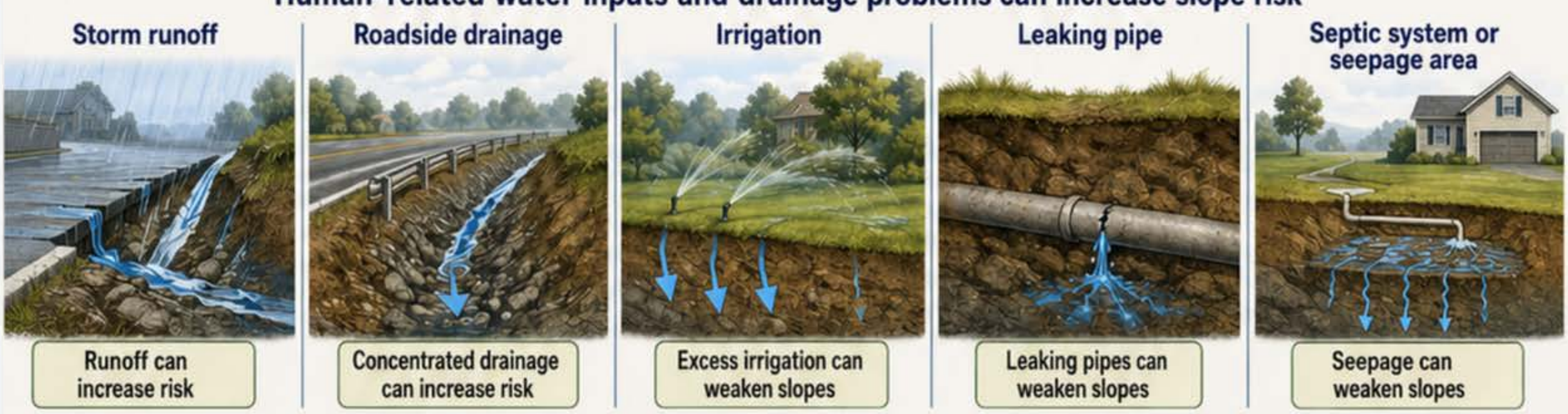
Water can add weight, reduce friction, and increase pressure inside the ground.



How Water Weakens the Internal Support of a Slope



Human-related water inputs and drainage problems can increase slope risk



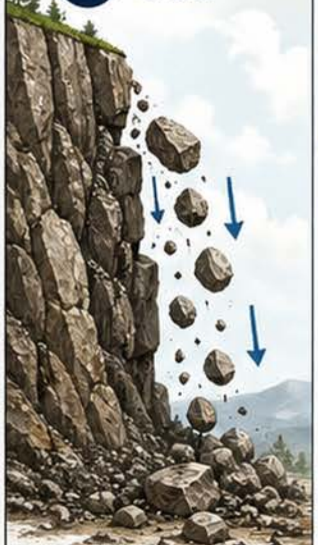
Policy takeaway: Water is often the trigger for slope failure.
Stormwater management, drainage design, irrigation, leaking infrastructure, and septic systems can all affect slope stability.

Landslides Are Not All the Same

Different landslide types move in different ways and require different responses.

MOVEMENT STYLE MATTERS

1 Fall



Rocks drop from a steep slope.

2 Slide

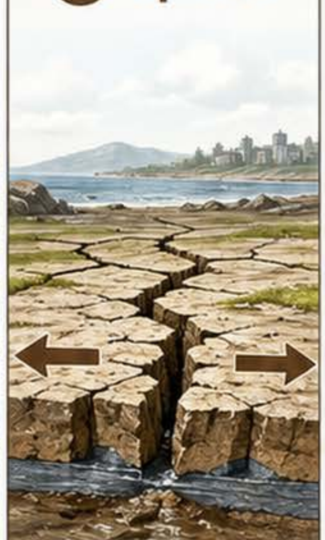
Material moves along a slide surface.

3 Flow

Wet material flows downhill.

mud/debris flows

4 Spread



Ground pulls apart and spreads.

5 Creep

Slow movement over time.

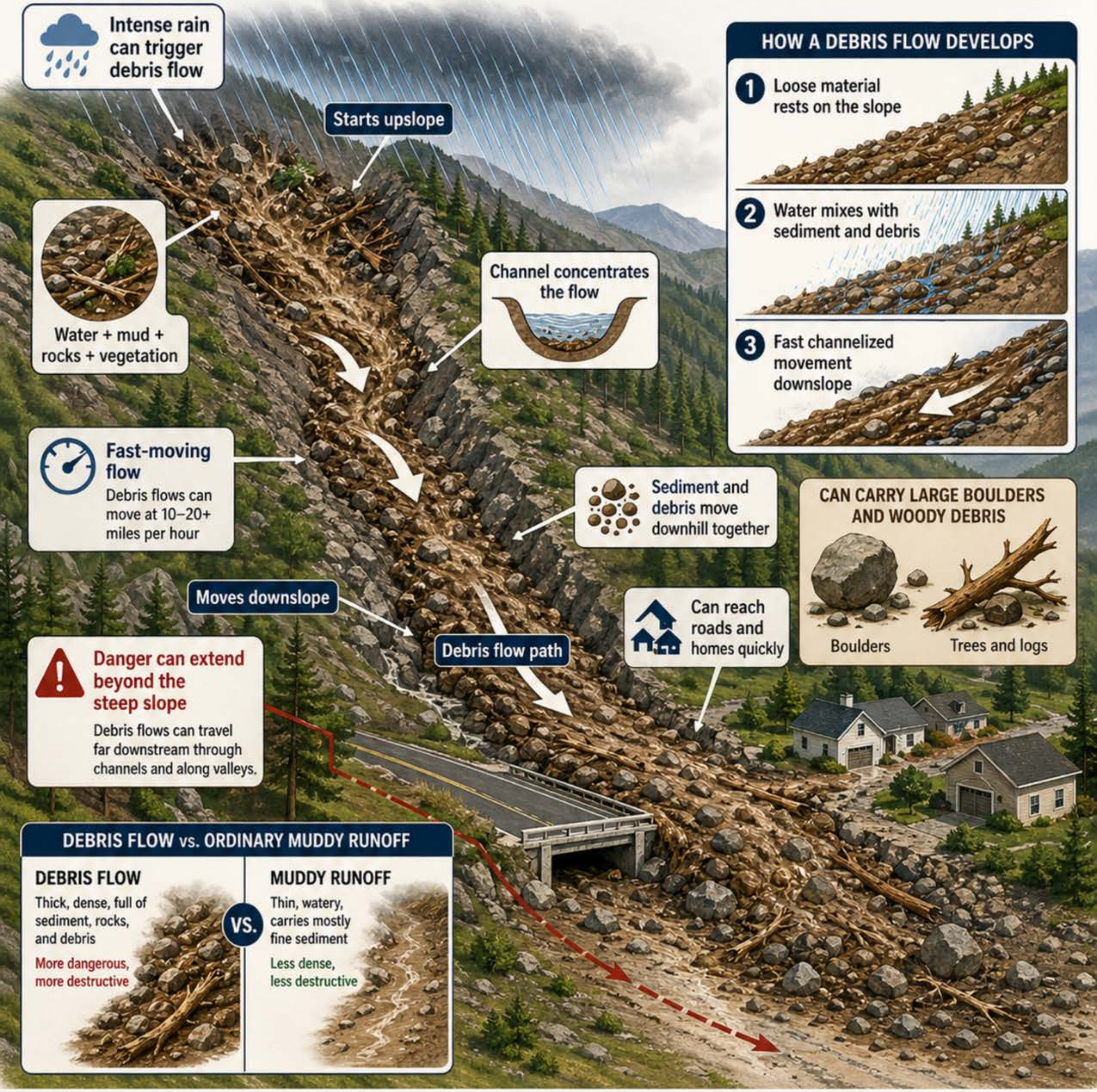
DIFFERENT TYPES CREATE DIFFERENT RISKS

	Fall	Slide	Flow	Spread	Creep
SPEED	Very fast (seconds)	Fast to moderate (minutes–hours)	Very fast (minutes)	Fast to moderate (hours–days)	Very slow (months–years)
MATERIAL	Rock, boulders, debris	Soil, rock, or both	Wet soil, silt, sand, debris	Soil or rock over weak layer	Soil, rock, engineered fills
MOVEMENT STYLE	Falls vertically	Slides along a surface	Flows like a fluid	Moves laterally (sideways)	Gradual, downslope movement
IMPACTS	Impact, damage, blockage	Burial, destruction, road damage	Burial, flooding, erosion	Ground failure, infrastructure damage	Damage to structures, utilities, roads

Policy takeaway: The type of landslide matters. *Monitoring, warning systems,* engineering design, setbacks, and emergency response should match how the ground is likely to move.

What Is Debris Flow and Why It Moves So Fast?

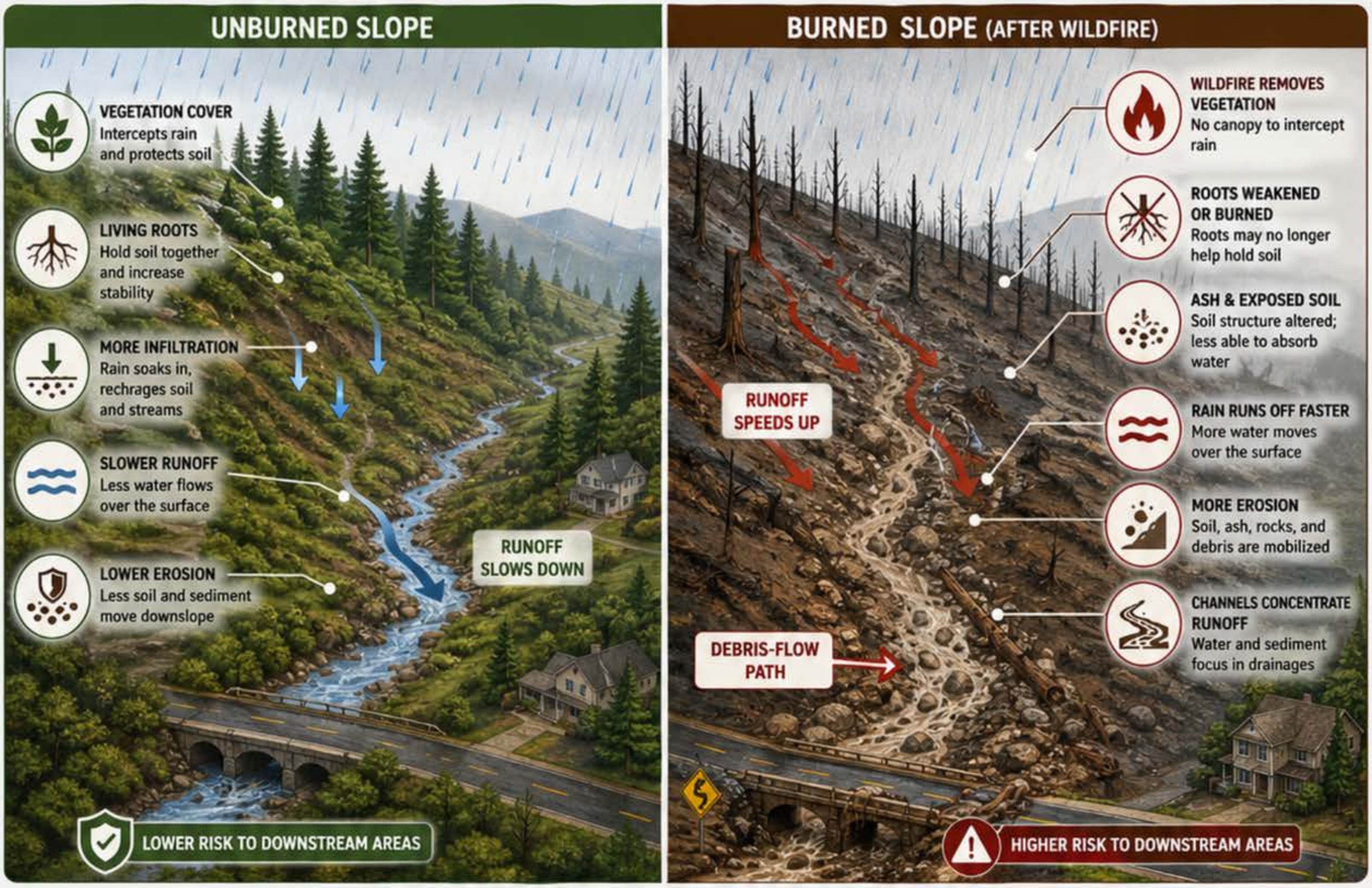
Debris flows are fast-moving mixtures of water, sediment, rock, vegetation, and other debris that travel downslope, often through channels, and can quickly reach roads, homes, and infrastructure.



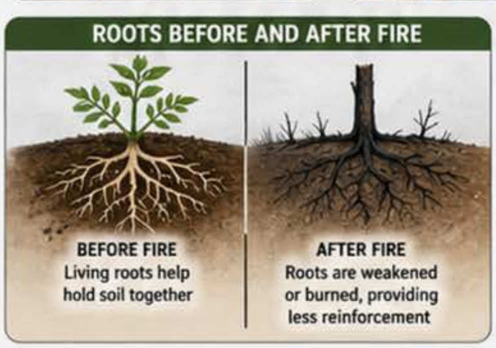
Policy takeaway: Debris flows can move quickly and travel far through channels. This matters for evacuation planning, post-fire response, road closures, culvert design, and warning systems.

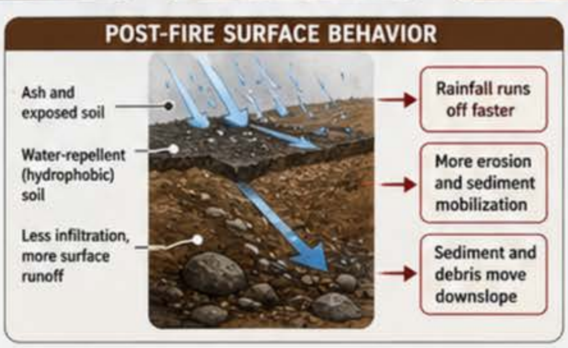
WHY WILDFIRE INCREASES LANDSLIDE AND DEBRIS-FLOW RISK

Burned slopes can shed water and sediment rapidly because vegetation is removed, roots are weakened, and soil behavior is altered after wildfire.



FROM FIRE TO FLOOD: POST-FIRE HAZARD SEQUENCE



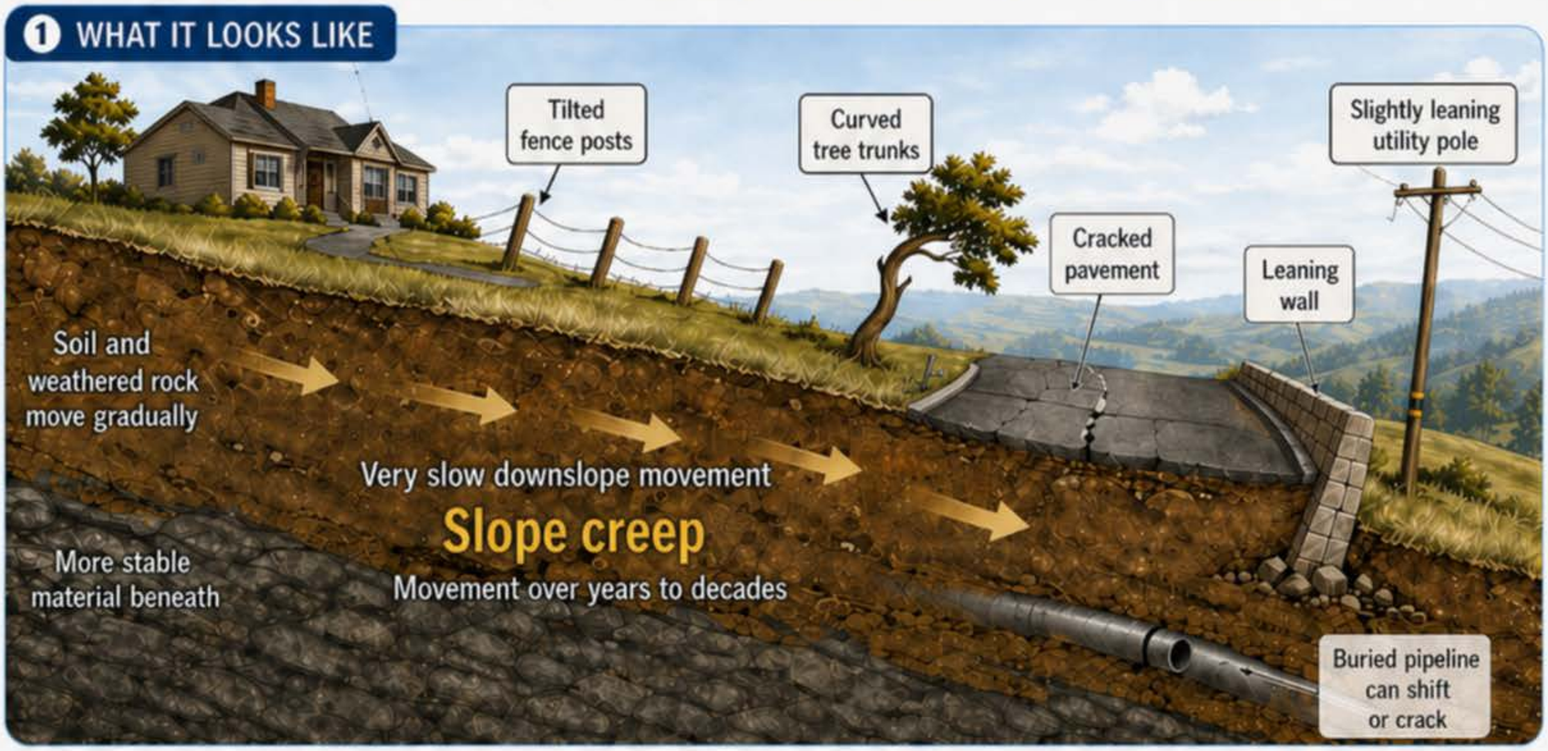


POLICY TAKEAWAY: After wildfire, slopes can shed water and sediment quickly during storms. Post-fire planning, emergency alerts, road closures, watershed recovery, and infrastructure protection should begin **before heavy rain arrives.**

What Is Slope Creep?

Soil and weathered rock can move very slowly downslope over years to decades.

1 WHAT IT LOOKS LIKE



2 SIGNS AT THE SURFACE

Tilted fence posts
Fences no longer stand upright.

Curved tree trunks
Trees grow in a curved shape.

Cracked pavement
Small cracks form and widen over time.

Leaning walls
Retaining walls tilt or bulge outward.

Shifted utilities
Pipes and poles can move or crack.

3 MOVEMENT OVER TIME

Year 1 ⟶ Year 10 ⟶ Year 30

Changes are gradual and easy to overlook. The effects add up over decades.

4 WHY IT HAPPENS

Natural processes slowly weaken and move soil and weathered rock.

Repeated wetting and drying

Water softens soil; drying causes shrinkage and cracking.

Freeze–thaw and expansion–contraction

Temperature changes cause ground to expand and contract.

5 WHY IT MATTERS: SLOW GROUND MOVEMENT CAN DAMAGE INFRASTRUCTURE

Roads

Cracks, bumps, and drainage problems.

Foundations

Uneven settlement and structural stress.

Retaining Walls

Walls can tilt, crack, or fail over time.

Pipelines

Joints can separate or pipes can break.

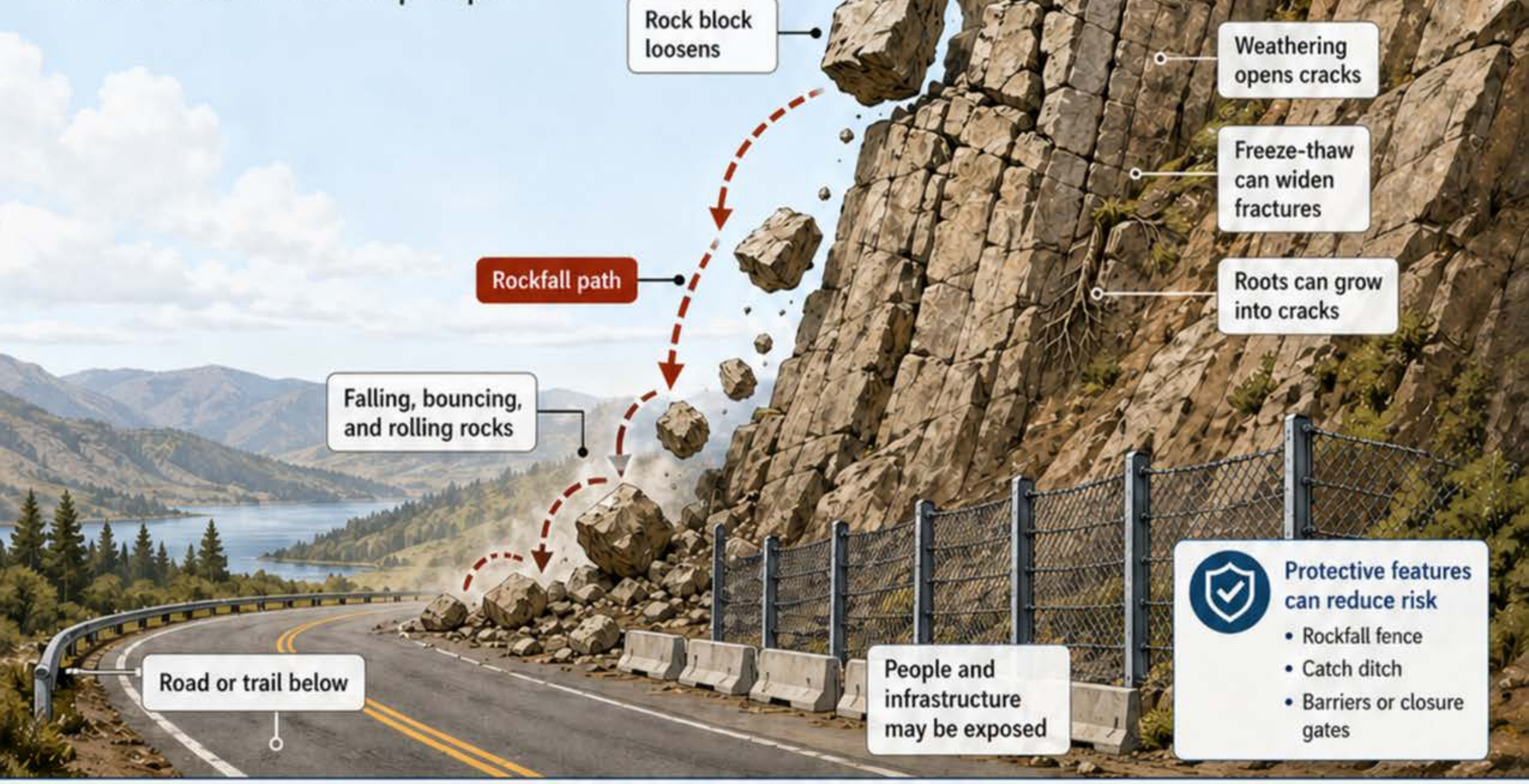
Utilities

Poles, lines, and boxes can shift or be damaged.

POLICY TAKEAWAY: Slope creep is slow, but it can still damage roads, foundations, retaining walls, pipelines, and utilities over time.
Long-term monitoring and maintenance matter even where no sudden landslides have occurred.

How Rockfalls Happen

Rockfalls occur when fractures and triggers loosen blocks from steep slopes.



HOW A ROCKFALL DEVELOPS

1 Cracks form

Fractures break the rock into blocks.

2 Triggers weaken the block

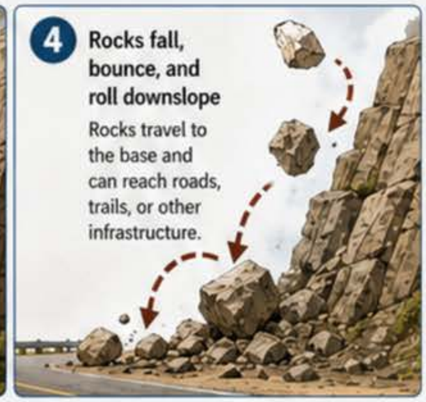
Weathering and other processes open cracks and reduce strength.

3 Block detaches

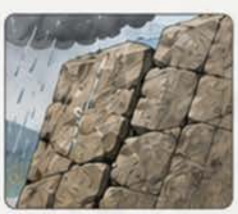
A trigger releases the block from the slope face.

4 Rocks fall, bounce, and roll downslope

Rocks travel to the base and can reach roads, trails, or other infrastructure.



COMMON TRIGGERS THAT CAN RELEASE ROCK BLOCKS



Weathering
Rain, wind, and temperature changes break down rock. and open cracks.

Freeze-thaw
Water gets into cracks, freezes, and expands—widening fractures over time.

Root growth
Tree and plant roots can grow into cracks and pry rock blocks apart.

Earthquake shaking
Ground shaking can suddenly trigger movement and cause failure.

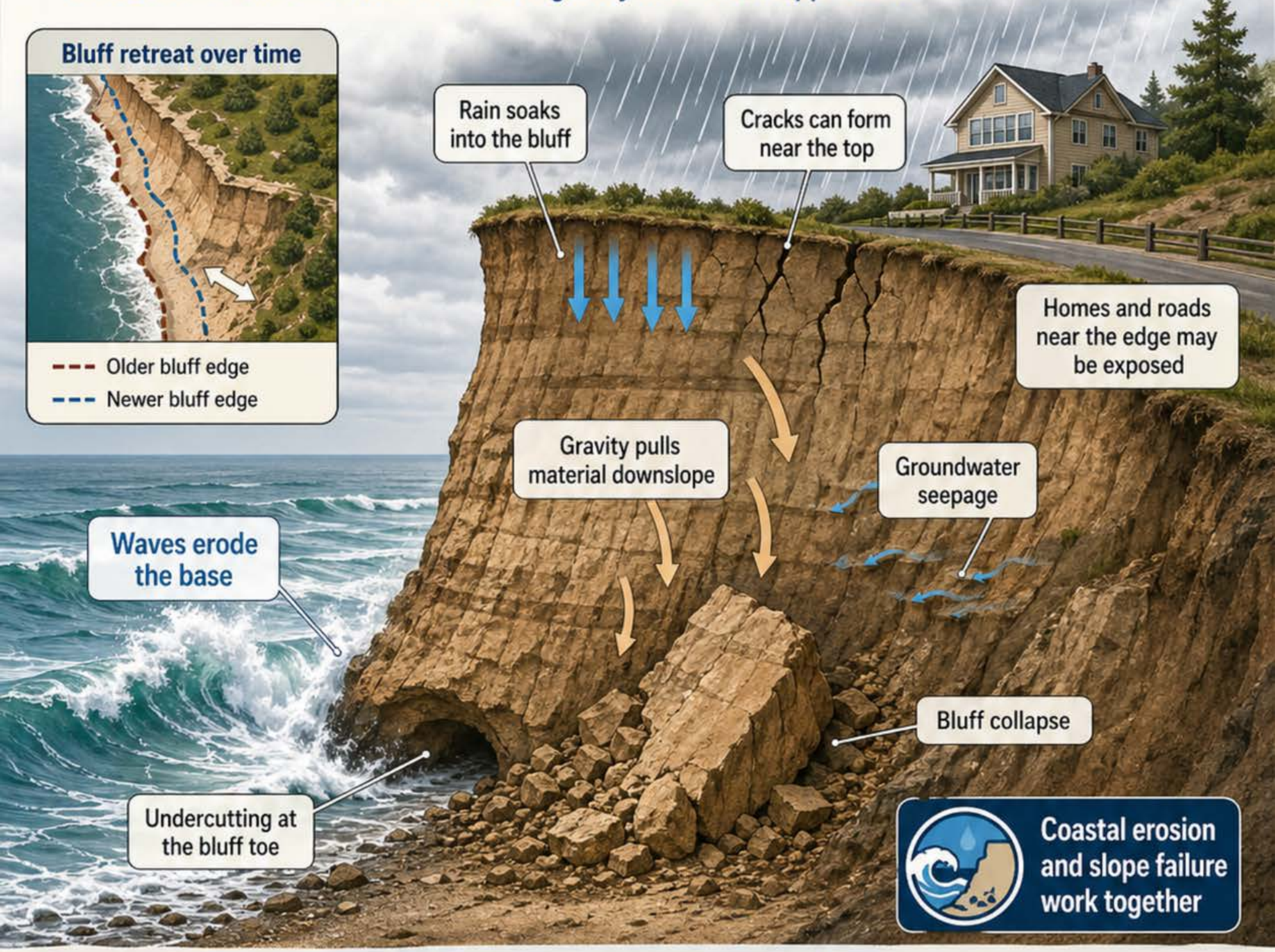
Erosion / undercutting
Streams, waves, or runoff remove support at the base, making slopes unstable.

Road cuts / excavation
Cutting into slopes steepens them and removes support, increasing risk.

POLICY TAKEAWAY: Rockfall hazards matter where steep rocky slopes overlook roads, trails, parks, rail lines, or developed areas. Inspection, slope design, barriers, setbacks, and temporary closures can all help reduce risk.

Why Coastal Bluffs Collapse

Waves weaken the base while water and gravity weaken the upper bluff.



1 Waves erode the base

Waves remove sediment and undercut the bluff, weakening support at the base.

2 Rainfall and groundwater weaken the upper bluff

Water infiltrates, seeps, and creates cracks, reducing the strength of the bluff.

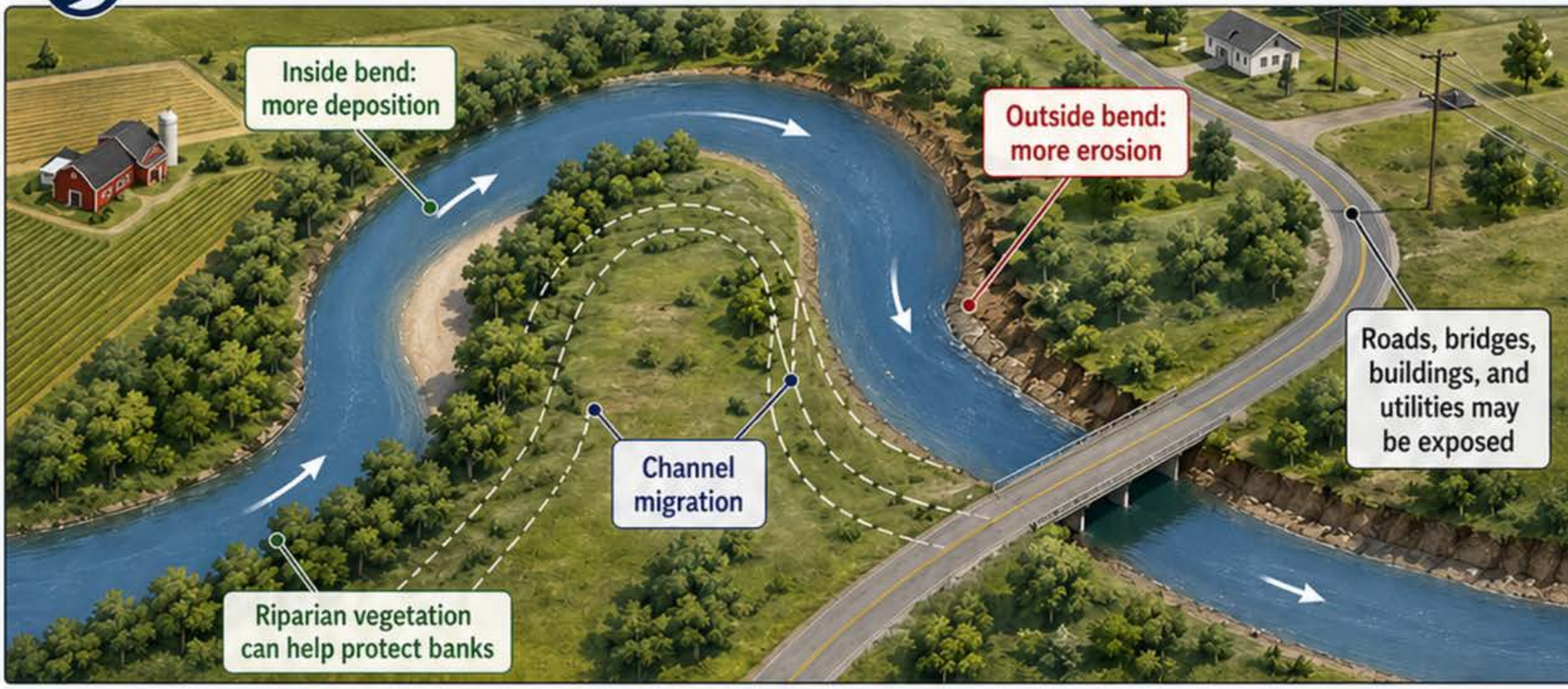
3 Bluff collapse and retreat occur

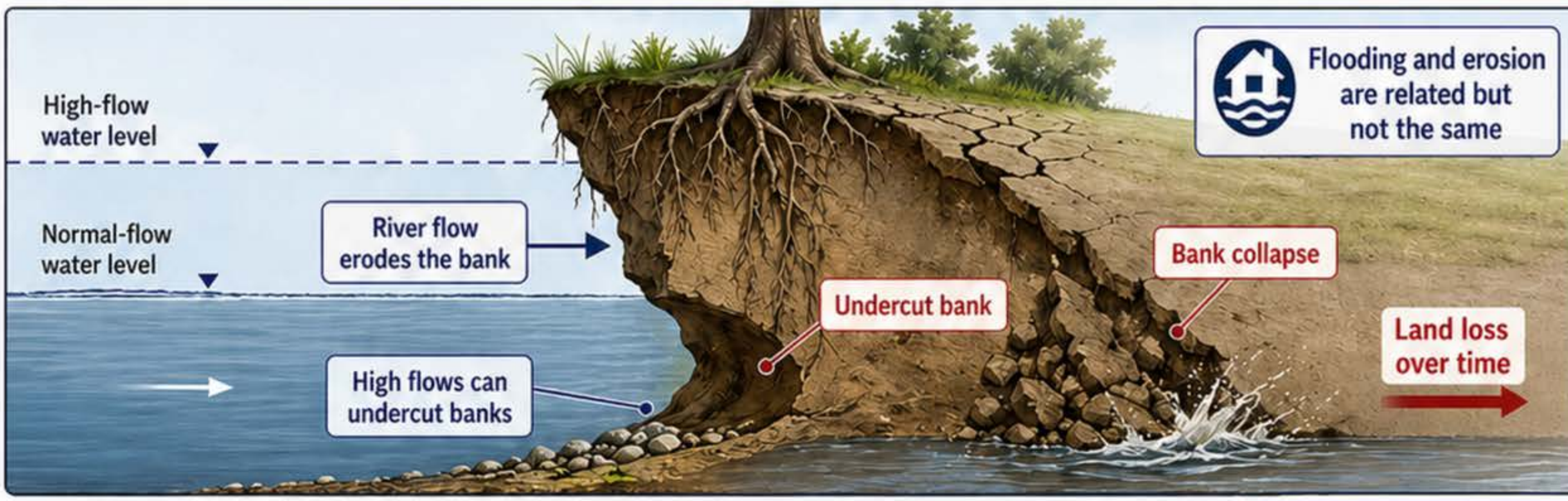
Gravity causes failure. The bluff retreats landward over time.

Policy takeaway: Coastal bluff collapse is driven by both shoreline erosion and slope instability. Setbacks, drainage control, infrastructure siting, and long-term shoreline planning all affect risk.

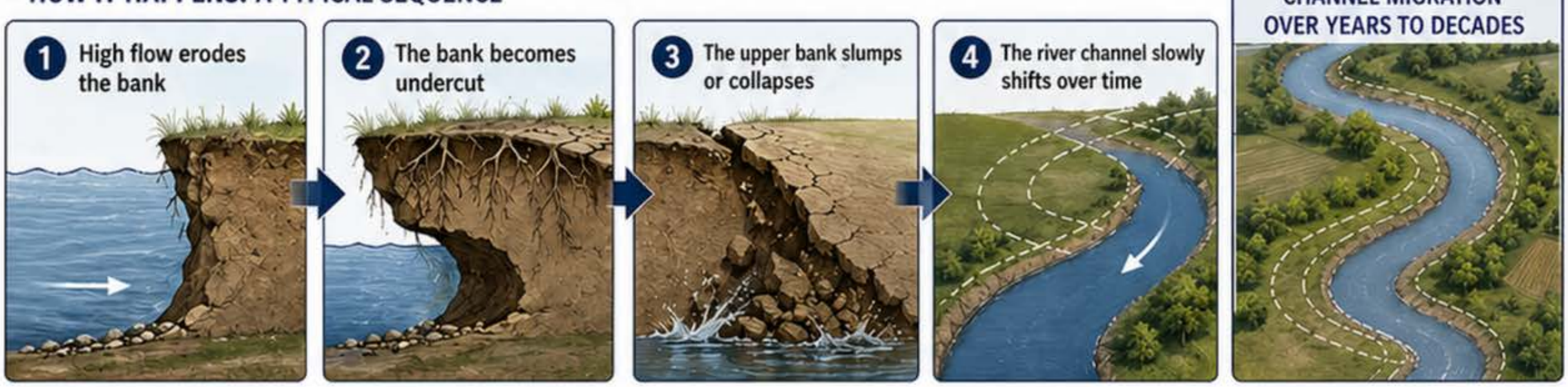
How Riverbank Erosion Causes Land Loss

Rivers naturally erode banks, especially during high flows and along bends.





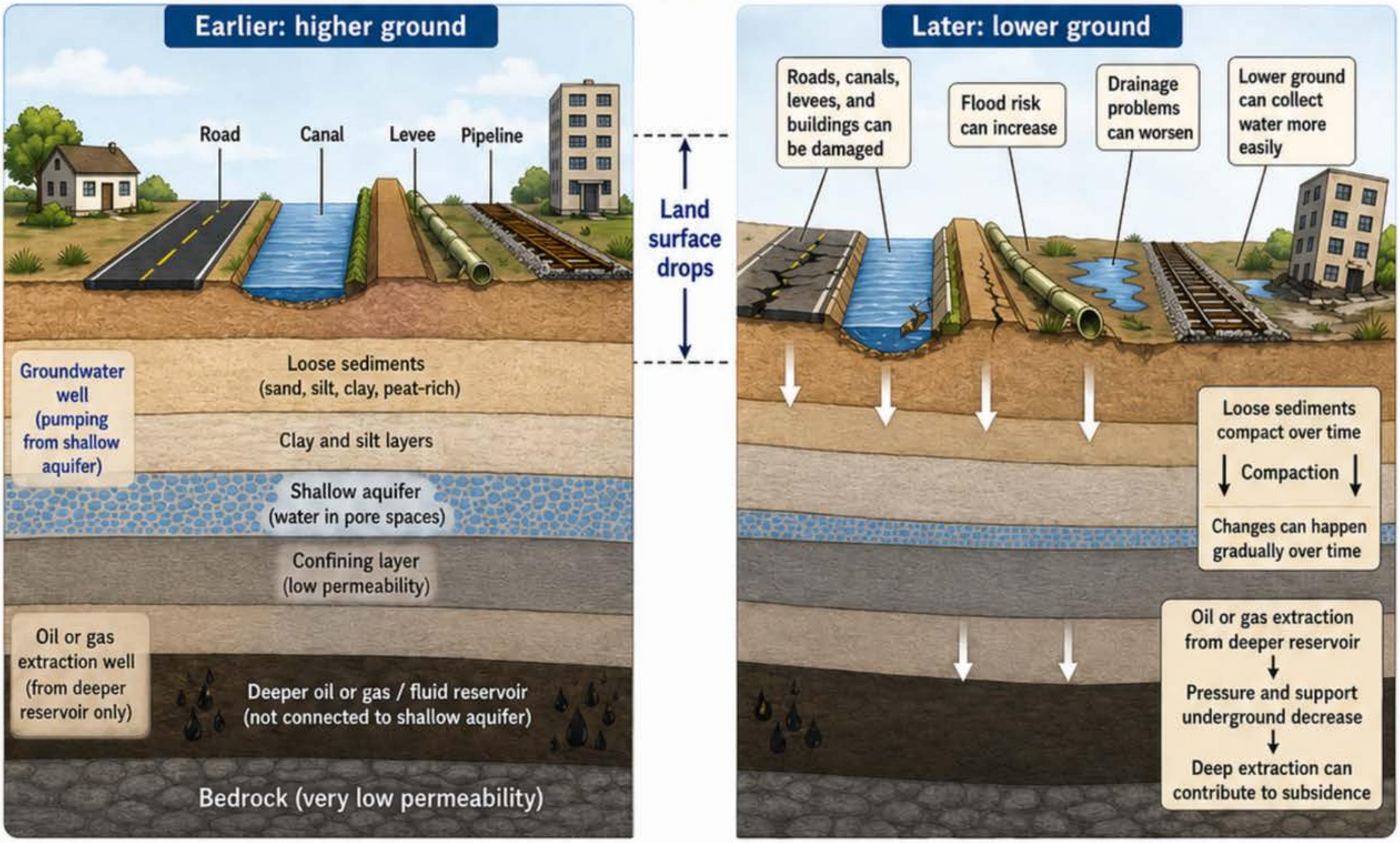
– HOW IT HAPPENS: A TYPICAL SEQUENCE



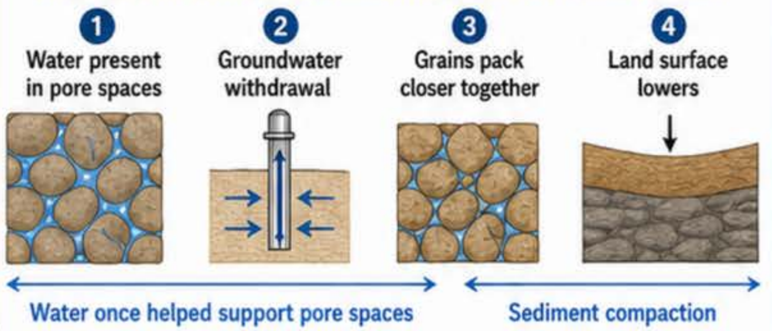
Policy takeaway: Riverbanks can move over time, especially during high flows and along bends. Floodplain planning, bridge and road siting, riparian buffers, setbacks, and property-risk communication should account for erosion as well as flooding.

What Is Subsidence?

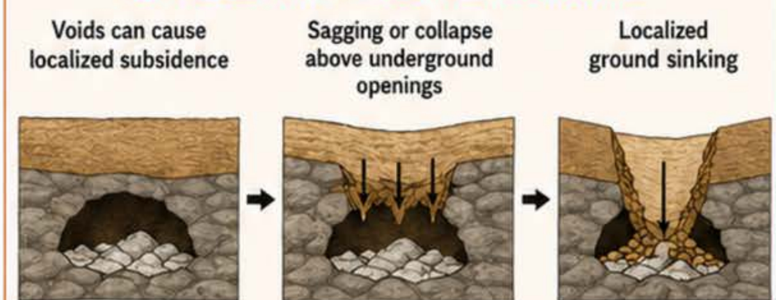
Subsidence is the sinking of the ground surface over time.



HOW GROUNDWATER WITHDRAWAL LEADS TO COMPACTION



LOCALIZED VOID-COLLAPSE SUBSIDENCE



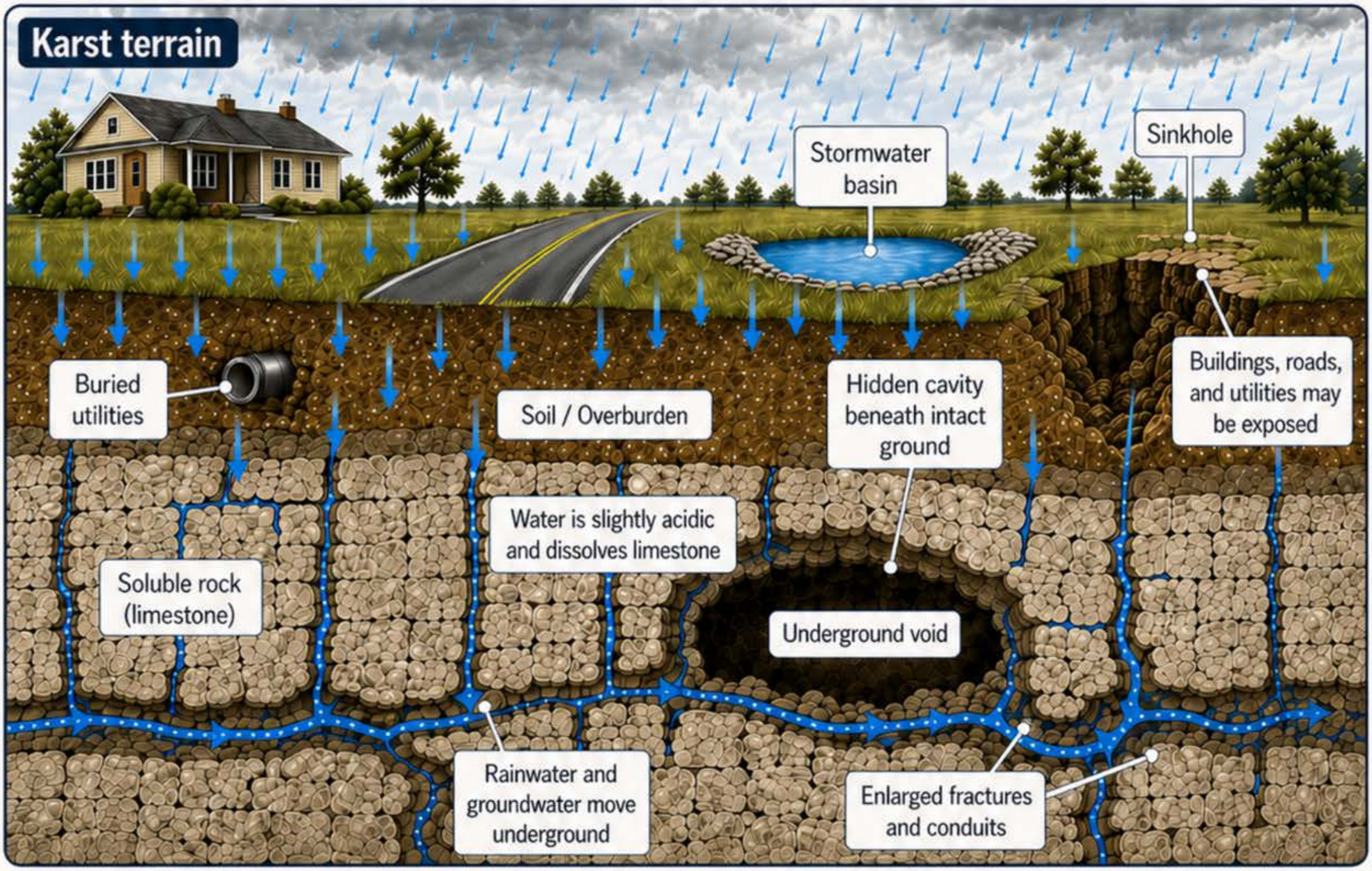
THREE WAYS SUBSIDENCE CAN HAPPEN

1	Groundwater withdrawal →	Compaction →	Broad sinking
2	Deep fluid extraction →	Settling →	Broad sinking
3	Underground voids →	Sagging / collapse →	Localized sinking

Policy takeaway: Subsidence can reshape flood risk, drainage, and infrastructure performance over time. Groundwater management, extraction practices, land-use planning, and infrastructure design all affect how communities respond.

Why Karst Terrain Can Produce Sinkholes

Soluble rock can dissolve underground, creating hidden voids that may lead to surface collapse.



How a sinkhole can form

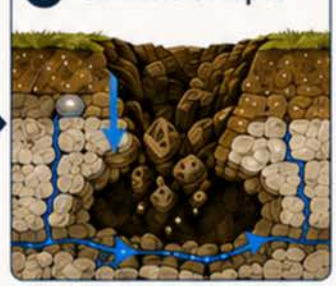
1 Dissolution

Slightly acidic water infiltrates through cracks and openings and dissolves limestone.

2 Hidden cavity

Dissolution enlarges fractures and creates a void. A soil bridge remains at the surface.

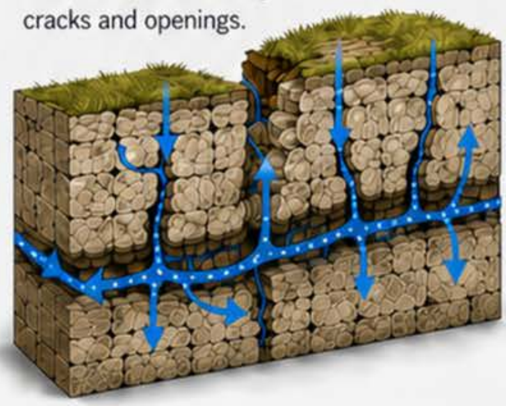
3 Sinkhole collapse



The soil bridge fails, and the ground collapses into the void, forming a sinkhole.

Groundwater movement in karst

Water can enter through cracks and openings.

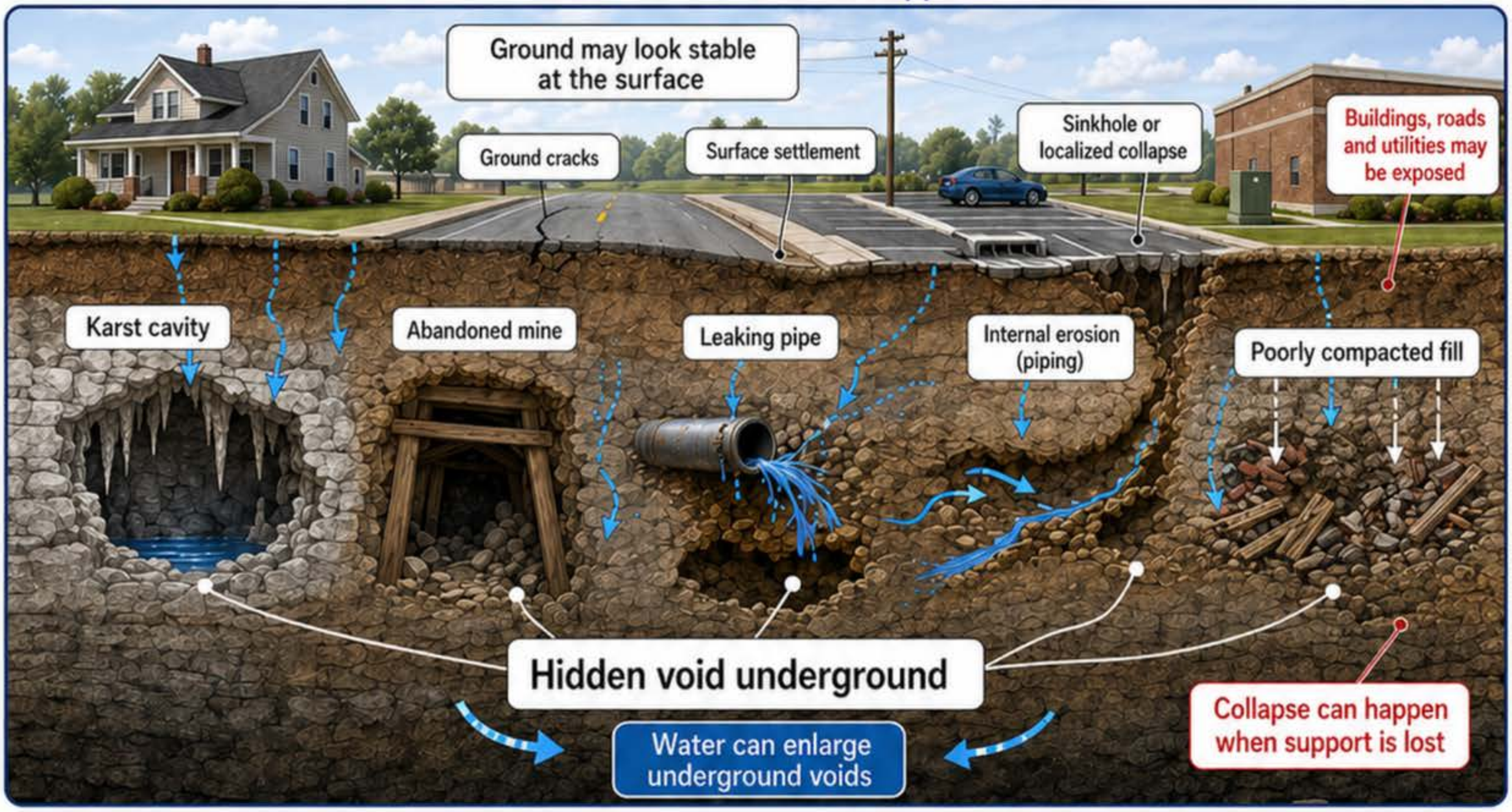


- Rainwater and groundwater move underground
- Limestone dissolves over time
- Hidden cavities may form below the surface
- Surface sagging or collapse can occur

Policy takeaway: In karst areas, underground conditions can strongly affect surface stability. Building codes, stormwater design, groundwater protection, and infrastructure siting should account for the possibility of sinkholes and hidden voids.

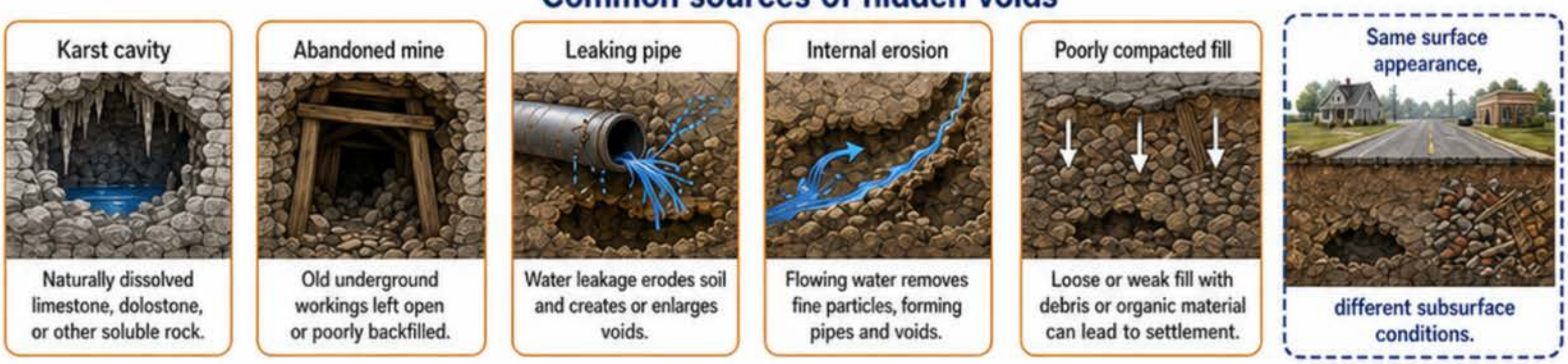
When the Ground Has Hidden Voids

Underground openings can form naturally or through human activity, even when the land surface appears stable.



How hidden voids can affect the surface

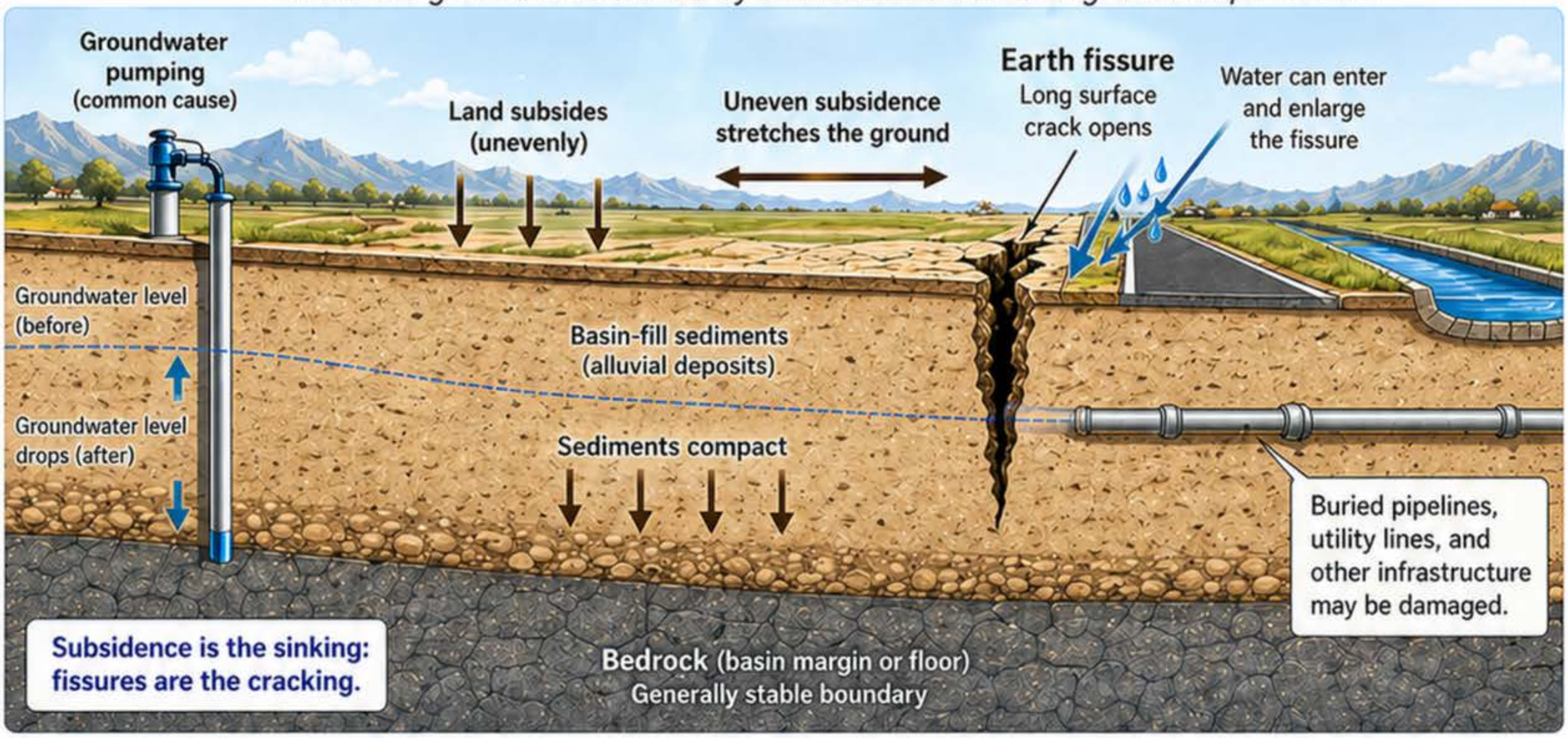
Common sources of hidden voids



Policy takeaway: Stable-looking surfaces may hide underground voids. Geotechnical investigation, mine-land records, karst mapping, stormwater controls, utility maintenance, and development review can help reduce the risk of unexpected settlement or collapse.

How Earth Fissures Form

Earth fissures usually form in basin-fill sediments or alluvial deposits where the ground is stretched by uneven subsidence or ground deformation.



1 Before major subsidence

2 Groundwater levels decline

3 Sediments compact and land subsides unevenly

4 Ground stretches and an earth fissure opens

1. Level land surface, intact sediments, and stable groundwater conditions.
2. Pumping lowers the groundwater level.
3. Sediments compact, causing land to sink. Subsidence is uneven across the basin.
4. Uneven subsidence stretches the ground and a long fissure opens at the surface.

Not the same as an ordinary drying crack

Earth fissure

- Long, deep opening
- Associated with subsidence and ground deformation
- Can damage infrastructure and reach great depths

Ordinary drying crack

- Small, shallow surface crack
- Caused by surface drying of soil
- Usually not deep or structurally damaging

Other processes can also contribute

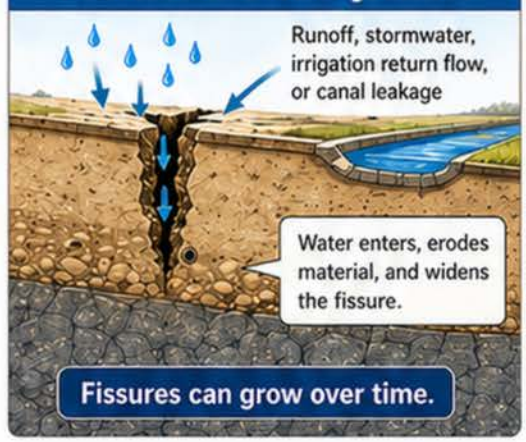
Groundwater pumping is a common cause, but other processes can also contribute.

Natural sediment compaction
Fine-grained sediments compact over time under their own weight or with aging.

Differential settlement or loading
Uneven loads from buildings, roads, or fills cause uneven settlement.

Subsurface extraction
Extraction of oil, gas, or minerals can cause ground subsidence.

Water can enter and enlarge fissures



Policy takeaway: Earth fissures can signal uneven subsidence and changing ground conditions. Groundwater management, subsidence monitoring, infrastructure planning, drainage control, and hazard mapping can help reduce long-term damage.

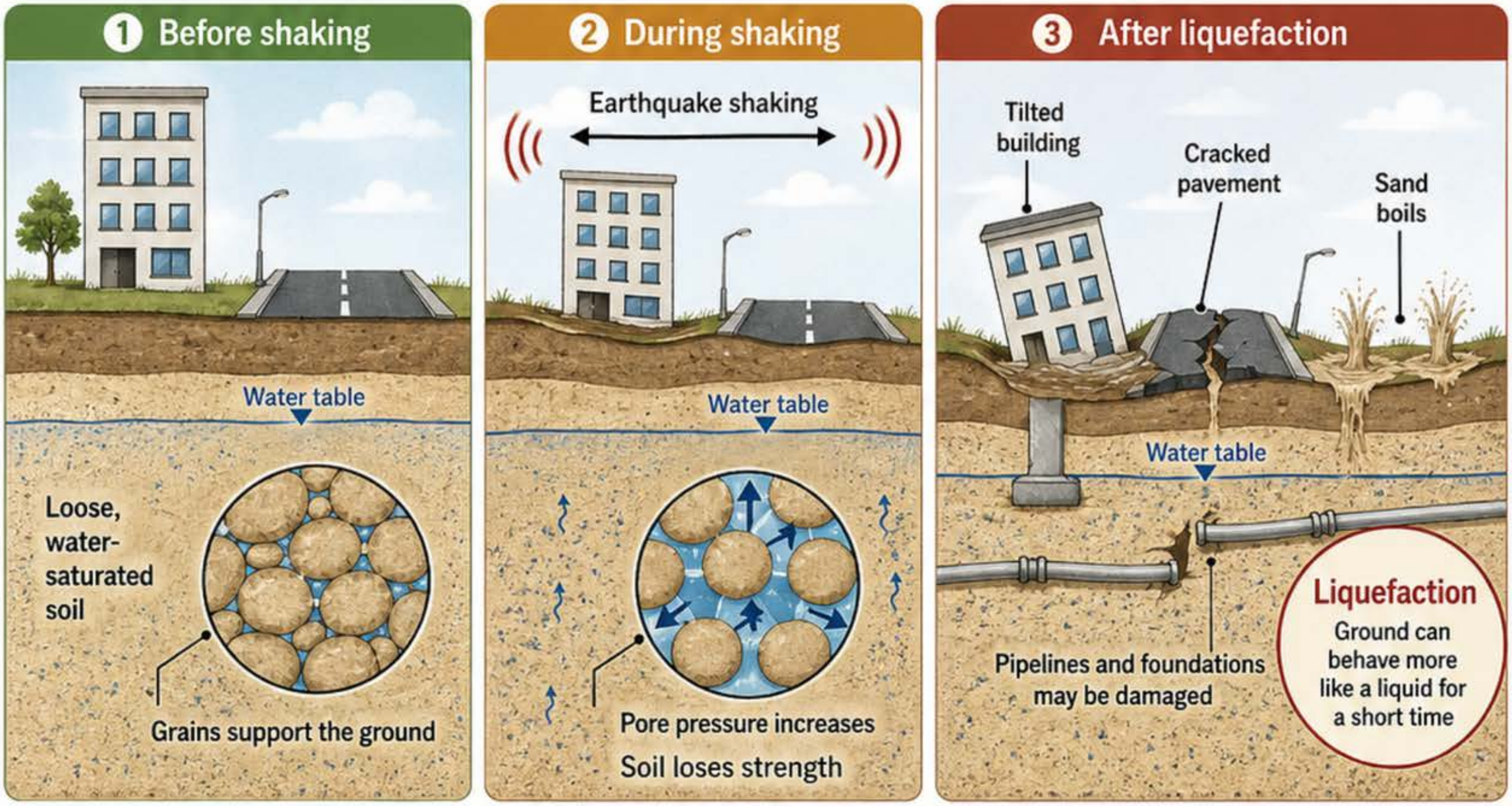
How Earthquakes Trigger Ground Failure

One earthquake can trigger different kinds of ground failure.

Policy takeaway: Earthquakes can damage communities by moving the ground itself, not just by shaking buildings. Seismic planning should account for landslides, rockfalls, liquefaction, and lateral spreading as well as structural design.

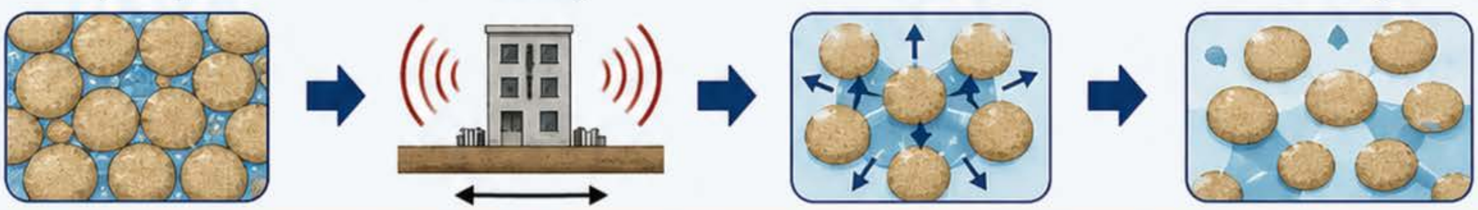
What Is Liquefaction?

Loose, water-saturated sandy or silty soil can temporarily lose strength during earthquake shaking.



How liquefaction works

1. Water in pore spaces
2. Earthquake shaking
3. Pore pressure increases
4. Temporary loss of strength



Where it is most likely

More likely in loose, young, water-saturated sediments

Near rivers · Coasts · Ports · Filled land

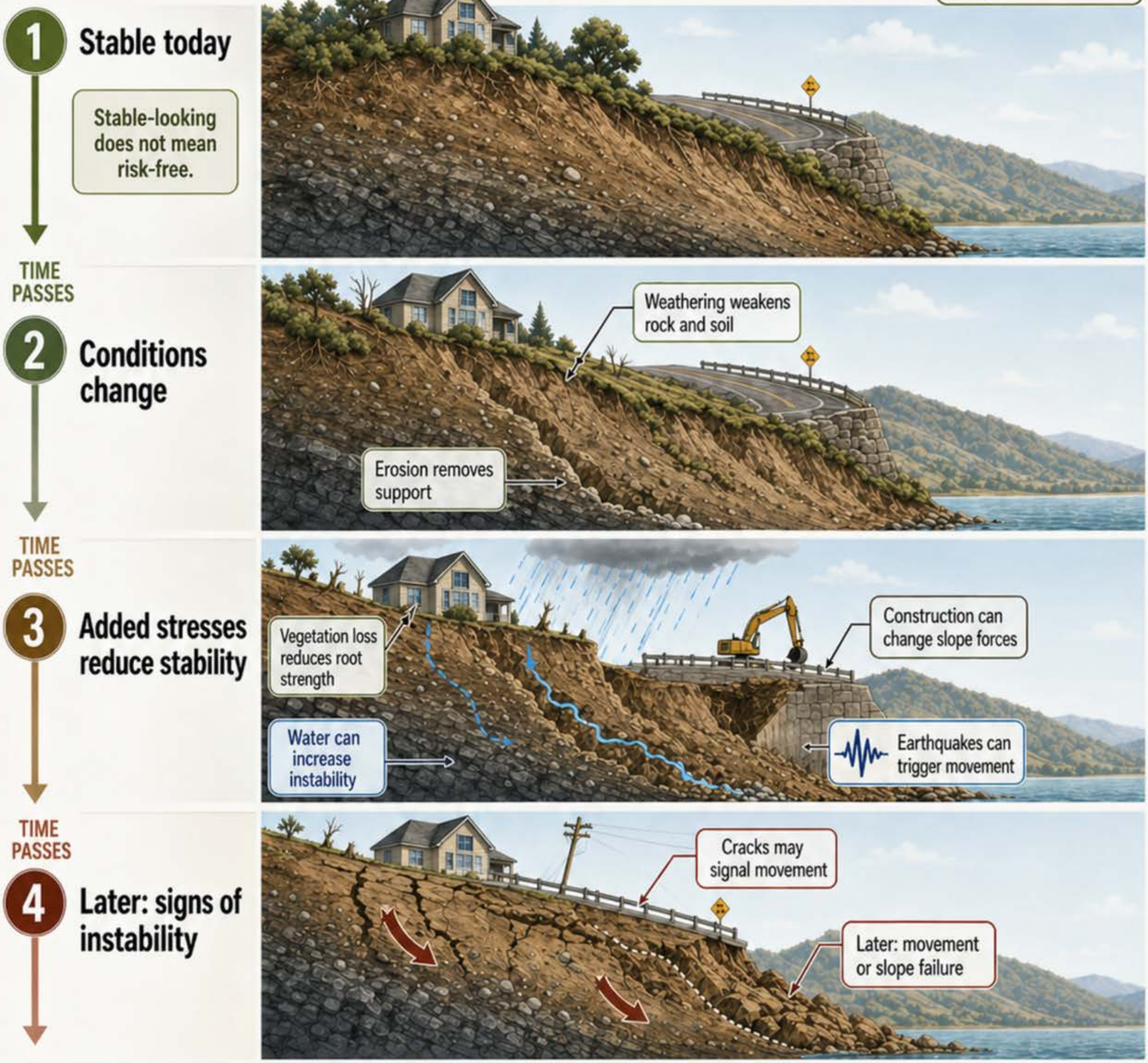
Policy takeaway:

Liquefaction can damage buildings and lifelines even where slopes are gentle. Building codes, port planning, bridge design, utility siting, and emergency planning should account for where loose, water-saturated soils are present.

Why ‘Stable Today’ Does Not Mean ‘Stable Tomorrow’

Slopes and ground conditions can change over time as small changes add up.

Conditions change over time

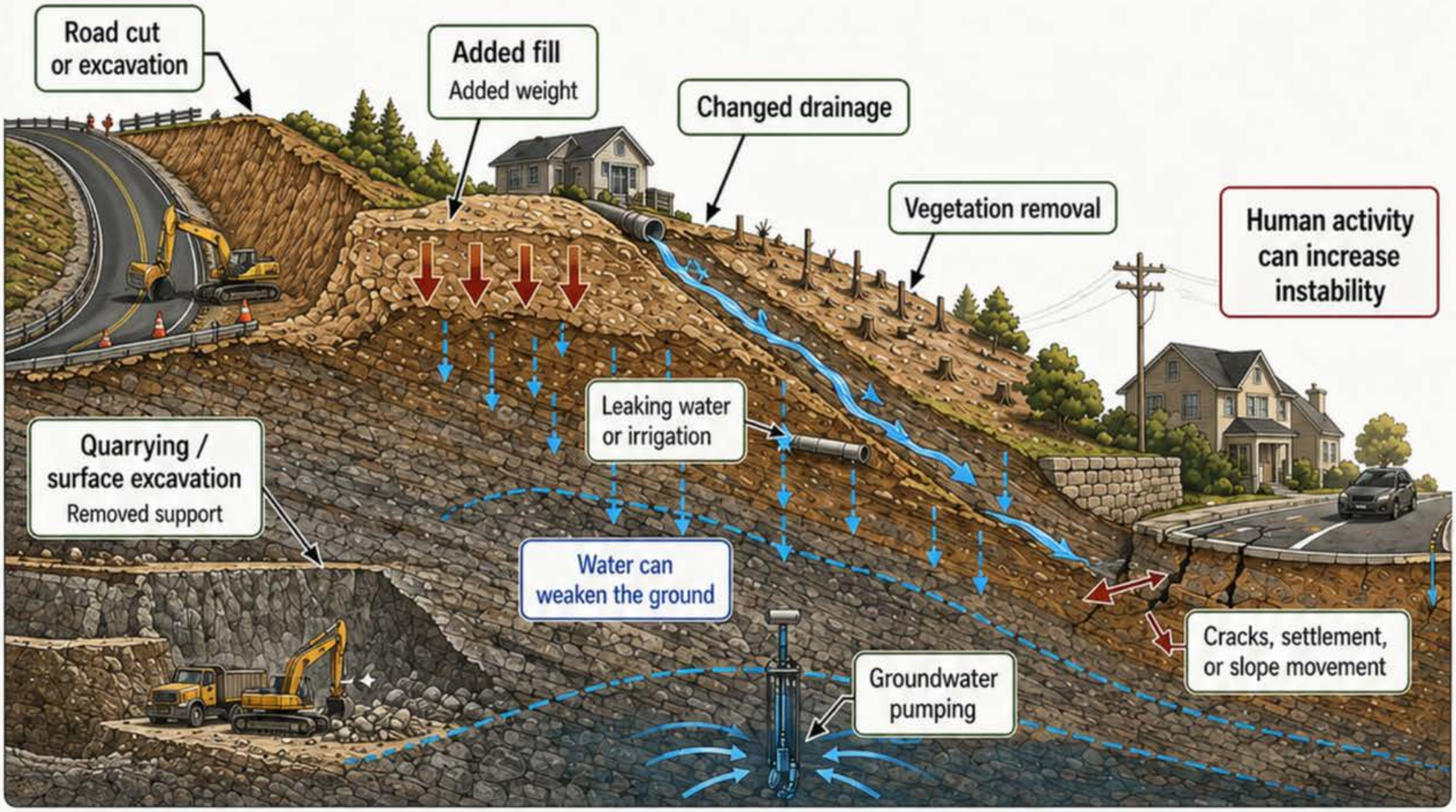


Small changes can accumulate

Policy takeaway: Slope stability changes over time. Monitoring, maintenance, updated hazard information, drainage management, and risk-based land-use planning help communities respond before small changes become larger problems.

How Human Activity Can Destabilize Land

Human actions can change the forces, water, and materials that control land stability.



1 Before disturbance

Stable slope with natural vegetation and drainage.

2 Human modification

Grading, fill, drainage changes, water addition, or excavation.

3 Reduced stability

Cracks, settlement, and slope movement increase risk.

Main pathways

Policy takeaway: Land instability is not always natural. Permitting, grading, drainage standards, vegetation management, mining oversight, and groundwater management all affect how human activity increases or reduces risk.

Hazard, Exposure, and Risk Are Not the Same

Unstable ground is the hazard. Exposure and vulnerability help determine risk.

1 Hazard

Hazard = unstable ground

2 Exposure

Exposure = people, buildings, roads, and utilities in harm's way

3 Risk

Risk = likelihood of harm + consequences

Hazard = unstable ground **+**

Exposure = people and things in harm's way **+**

Vulnerability = how easily they can be harmed **=**

Risk = chance of harm + consequences

Maps may show hazard, not full risk.

- Landslide hazard zone
- Buildings
- Road
- Stream

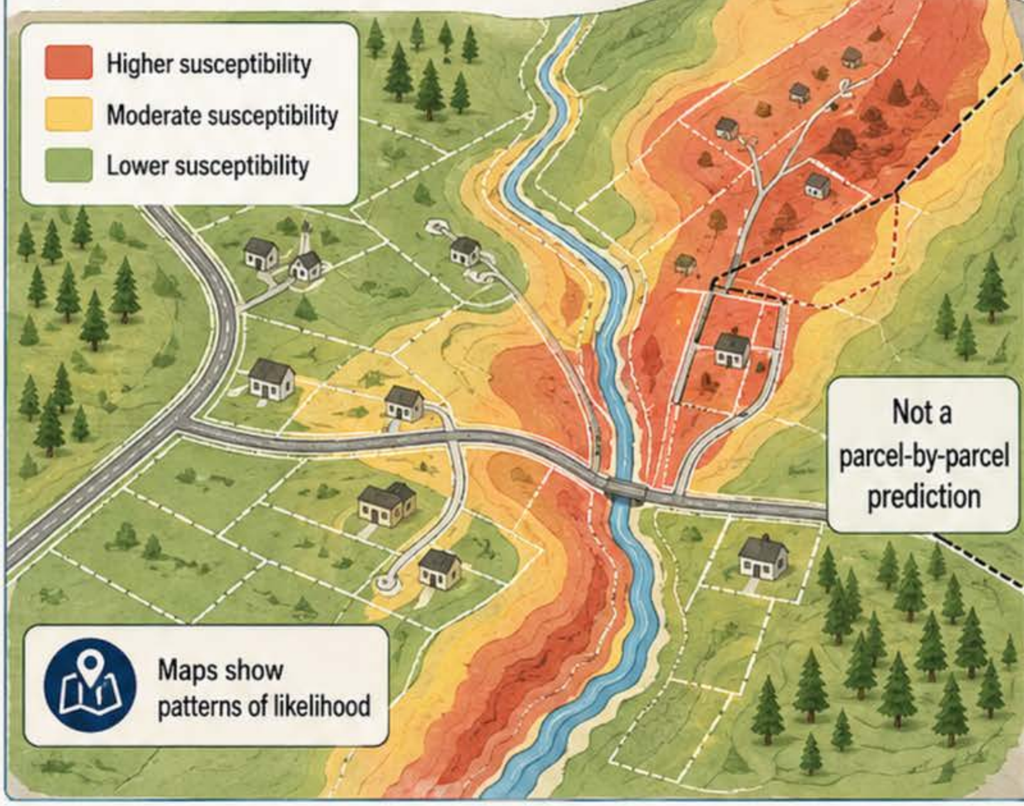
Risk depends on what is in harm's way.

The same hazard can mean different levels of risk in different places.

Policy takeaway: Hazard maps show where unstable ground may occur, but risk depends on who and what is exposed. This distinction helps agencies interpret maps, communicate clearly, and prioritize mitigation funding. Risk reduction can happen by reducing exposure, strengthening infrastructure, changing land use, improving warnings, or reducing the hazard where possible.

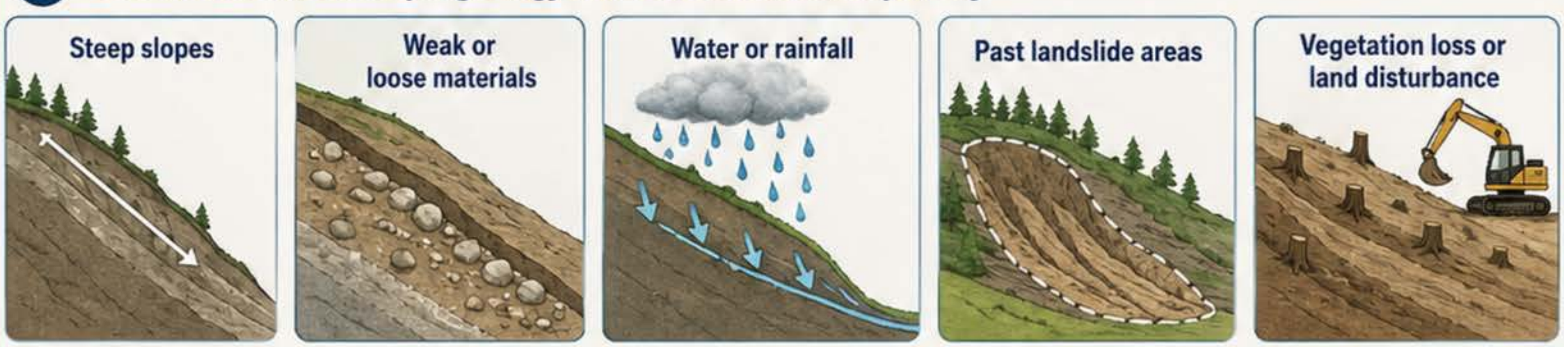
Why Landslide Maps Show Susceptibility, Not Certainty

1 Landslide susceptibility map



2 Zoom in: parcel examples

3 Conditions such as slope, geology, and water affect susceptibility



4 Susceptibility

- More likely / less likely
- Helps guide planning, screening, and communication

VS.

Certainty / exact prediction

- Maps do not predict exactly when or where a landslide will occur
- Site-specific review may still be needed

Susceptibility is not certainty.

Policy takeaway: Susceptibility maps are tools for screening and planning, not exact forecasts. They help guide planning, screening, communication, and where more site-specific investigation is needed.