Subsidence

Subsidence is the ***sinking or collapse of a portion of the land surface***.

The movement involved in subsidence is essentially **vertical**; little or no horizontal motion is involved.

It may take the form of

a **sudden**, **dramatic collapse** or

a **slow**, almost **imperceptible lowering**.

Carbonate Dissolution and Karst Topography

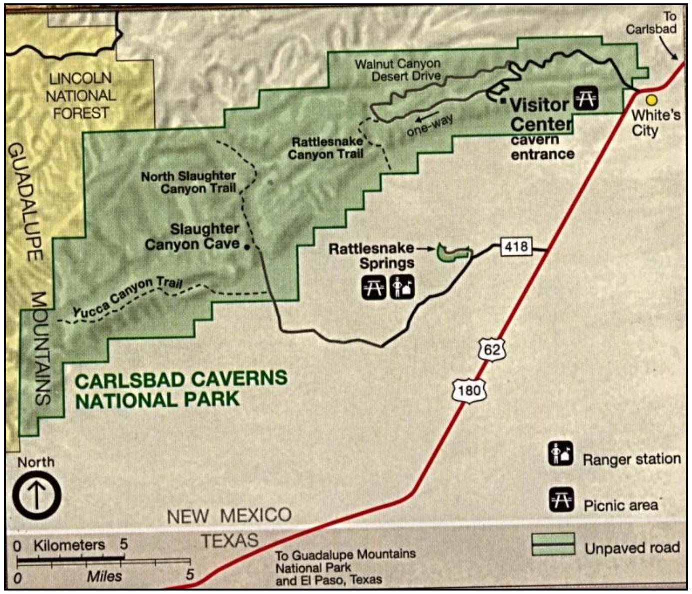
Dissolution

Caves are ***large underground open spaces***.

Caves come in many shapes and sizes.

A ***large cave or system of interconnected cave chambers*** is called a **cavern**.

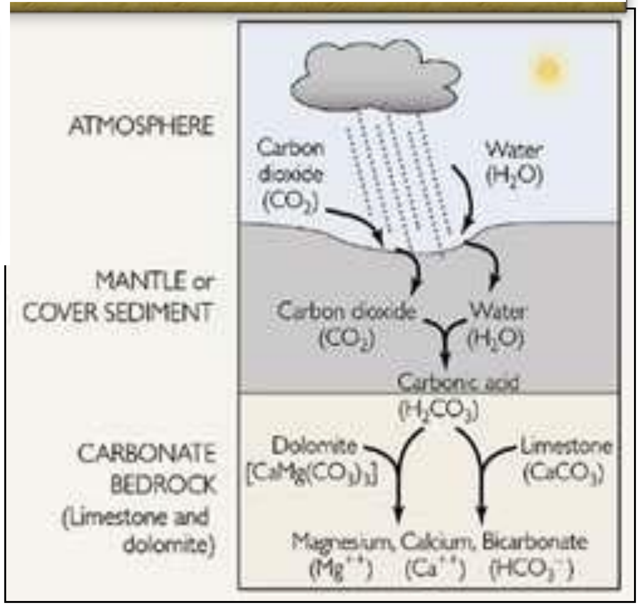
The **Carlsbad Caverns** in **southeastern New Mexico** include a chamber that is **1200 m long**, **190 m wide**, and **100 m high**.



Caves are formed through a **chemical weathering process** (**dissolution**) in which **carbonate rocks** are **dissolved** by **circulating groundwater**

Water (H_2O) falling through the atmosphere and percolating the ground **dissolves carbon dioxide (CO_2) gas** from the air and soil, forming **carbonic acid (H_2CO_3)**. As the carbonic acid infiltrates the ground and contacts the bedrock surface, it **reacts** readily with **limestone ($CaCO_3$)** and/or **dolomite ($CaMg(CO_3)_3$)**.

Caves develop as limestone or dolomite is **dissolved** into **component ions** of calcium (Ca^{++}), magnesium (Mg^{++}), and bicarbonate (HCO_3^-).



Dissolution of limestone or dolomite is most intensive along pre-existing openings in the rock, such as joints, fractures, and bedding planes.

When the groundwater becomes oversaturated with dissolved minerals, further dissolution is not possible

*and carbonate salts of calcium and magnesium may precipitate from the water, often forming interesting shapes such as **stalactites**.*

The **rate of cave formation** is related to the **rate of dissolution**.

In areas where the water is acidic, the **rate of dissolution increases** with **increasing velocity of flow**. As a passage grows and the flow becomes more rapid and turbulent, the **rate of dissolution increases**.

The development of a continuous passage by slowly percolating waters has been estimated to take up to **10,000 years**, and further enlargement of the passage by more rapidly flowing water to create a fully developed cave system may take an additional **10,000** to **1 million years**.

Karst Topography

Karst topography (after the **Karst region of the former Yugoslavia**) is ***topography characterized by many small, closed basins and a disrupted drainage pattern whereby streams disappear into the ground and eventually appear elsewhere in large springs***.

The most common type of karst terrain is **sinkhole karst**, a ***landscape dotted with closely spaced circular collapse basins of various sizes and shapes***.

In contrast to a cave, a **sinkhole** is a ***large dissolution cavity that is open to the sky***.

Some sinkholes are ***caves whose roofs have collapsed***; these are sometimes called **collapse sinkholes** (or **solution sinkholes**).

Others are formed at the surface in places where rainwater is freshly charged with carbon dioxide and hence is most effective as a solvent.

Some sinkholes are funnel shaped; others have high, vertical sides.

Some sinkholes are formed **catastrophically**.

The **sinkhole** in **Winter Park**, **Florida** was formed by the collapse of surface materials into a preexisting cavity in underlying carbonate rocks. The cavern was connected to near-surface rocks and unconsolidated overburden by an open, chimneylike passageway called an **aven**. Formation of the sinkhole was initiated by **raveling**, or ***gradual downward movement of unconsolidated material into the aven***. Raveling eventually left the roof materials unsupported; surface fractures began to develop and the roof eventually collapsed, filling the aven with sediment and debris.

Sinkhole formation, also, can be initiated by the ***sudden wholesale collapse of the bedrock "roof" into the underground void***, a process called **stoping**.

Removal of Solids and Mine-Related Collapse

There are other ways in which the removal of solid materials can create spaces underground that may result in **subsidence**.

Removal of Salt

Because **rock salt** (composed mainly of the mineral **halite**, **NaCl**) can be dissolved by groundwater, karst terrains and sinkholes can develop in areas underlain by salt as well as in carbonate terrains.

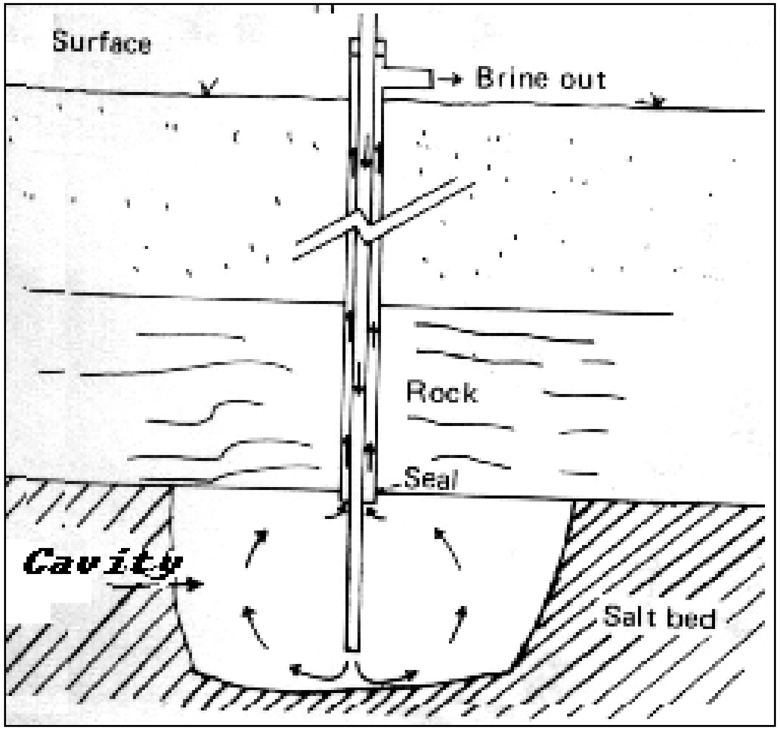
In **1980** a **sinkhole 110 m wide** and **34 m deep** developed in this manner near **Kermit**, **Texas**. This depression, called the **Wink Sink**, appeared without warning and grew to its full size within **48 hours**. Groundwater had dissolved caverns in underlying salt beds in much the same manner as that described earlier for carbonate terrains.

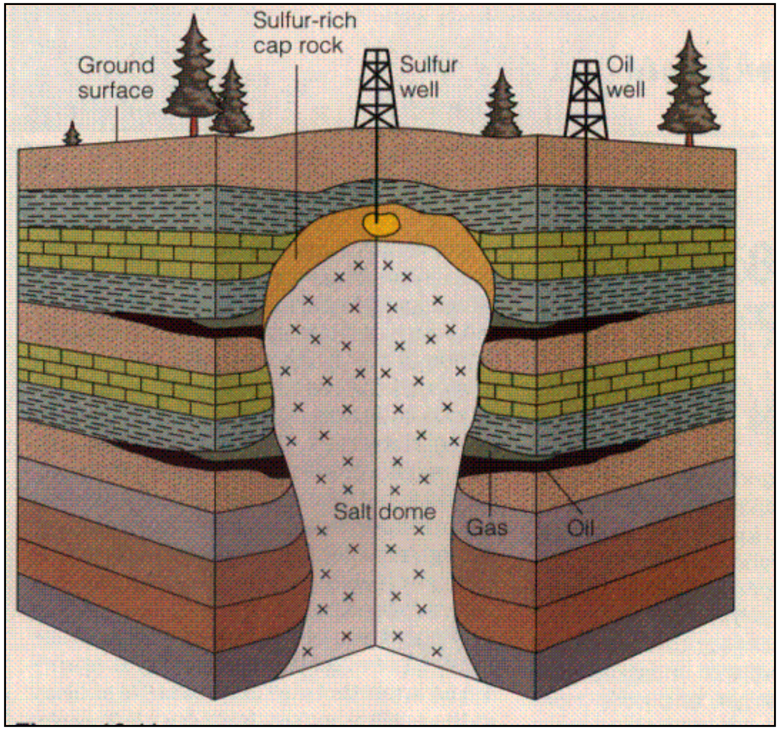
Wink Sink in 1980

Wink Sink in 2002

One technique used for **mining salt** is to ***inject fluids and induce dissolution of the salt underground so that it can be withdrawn in a liquid state***. This is called **solution mining**.

When the salt-saturated solution is pumped out it leaves **cavities in the rock**, thereby weakening the support for overlying material.

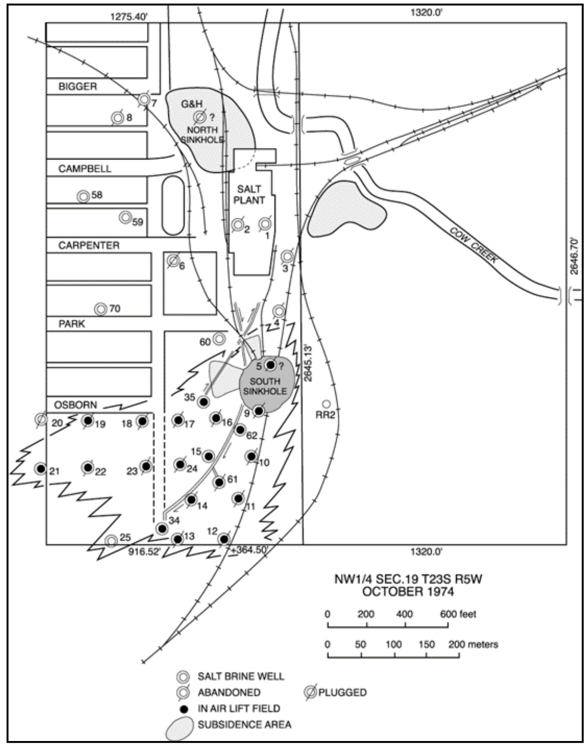




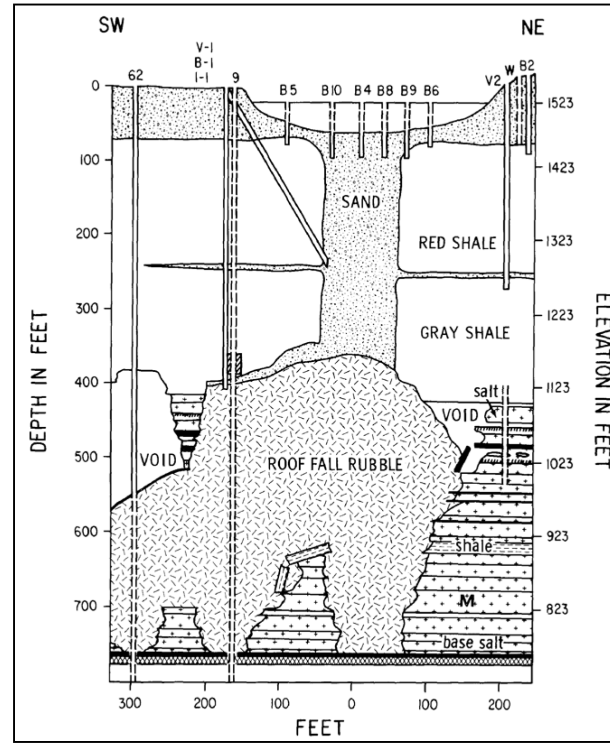
In **1974 solution mining** of salt was directly responsible for the rapid development of a water-filled sinkhole **300 m** in diameter in **Hutchinson, Kansas**.

Cargill Sinkhole – October 21, 1974

Cargill Sinkhole – November 12, 1974



Cargill Plant Layout, Showing North and South Sinkholes

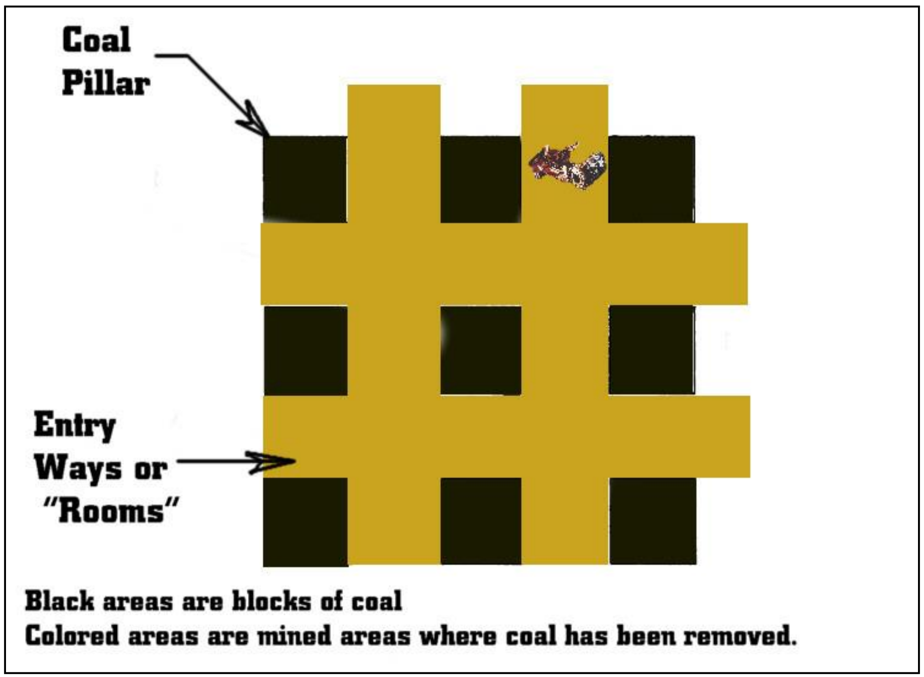


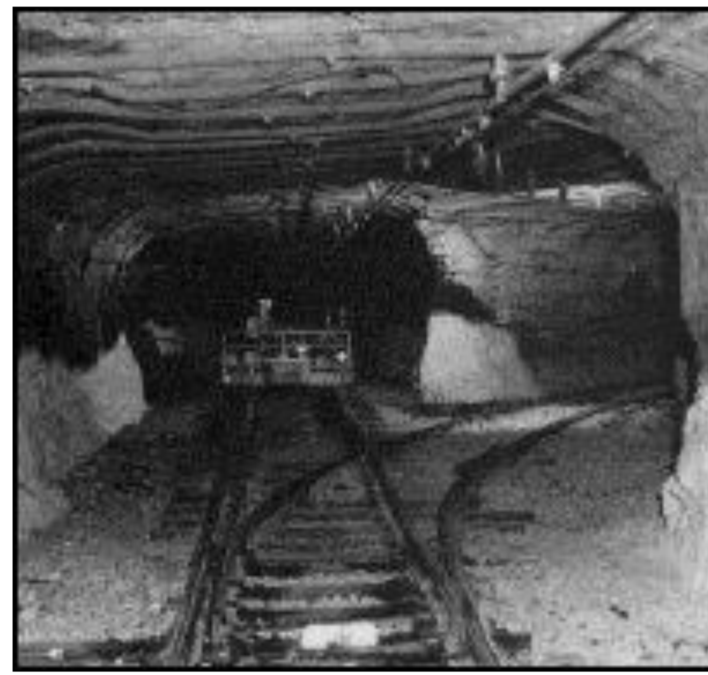
Cross Section Through South Sinkhole, Cargill Site

[redacted]

Areas in which **coal** is mined are susceptible to **subsidence**.

Coal is commonly mined underground using the "**room-and-pillar**" method, in which **large masses of coal are removed**, creating the "**rooms**," and **columns of coal are left behind** to form the supporting "**pillars**."





In the past, many mining companies removed as much coal as possible, even from seams relatively near the surface.

In some cases, **subsidence** occurred because **too much coal was removed**, and the pillars left behind could not support the weight of the overburden.

In other cases, the **mine was excavated too close to the surface** and the roof material between the pillars collapsed.

Some relatively recent episodes of **subsidence** can be attributed to **mining done 50 years ago or more**.

Grasslands near the **town of Sheridan**, **Wyoming**, are scarred and pitted with features resulting from subsidence of the ground surface into underground rooms from which coal was mined.

Most mining activities associated with the subsidence ended decades ago.

The pattern of the subsidence features reveals the layout of the underground rooms and pillars of the former mines.

Subsidence Caused by Fluid Withdrawal

Subsidence resulting from the **withdrawal of fluid** can be caused by **human activities**.

The fluids most often involved are **groundwater**, **oil**, **natural gas**, and associated **brines**, as well as **mixtures of stream and water used for geothermal energy**.

Water, Oil, and Gas

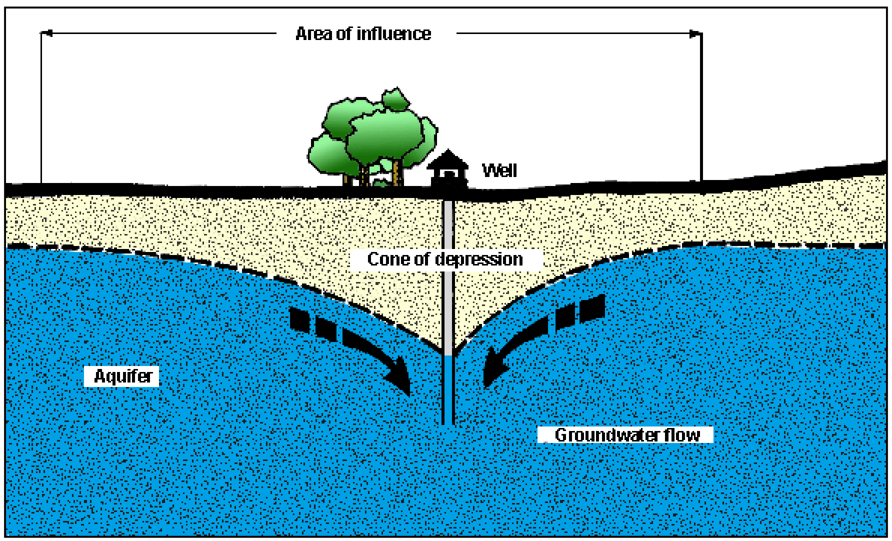
Subsidence is often caused by **removal of subsurface water**, especially if the rate of removal is faster than the rate of replenishment.

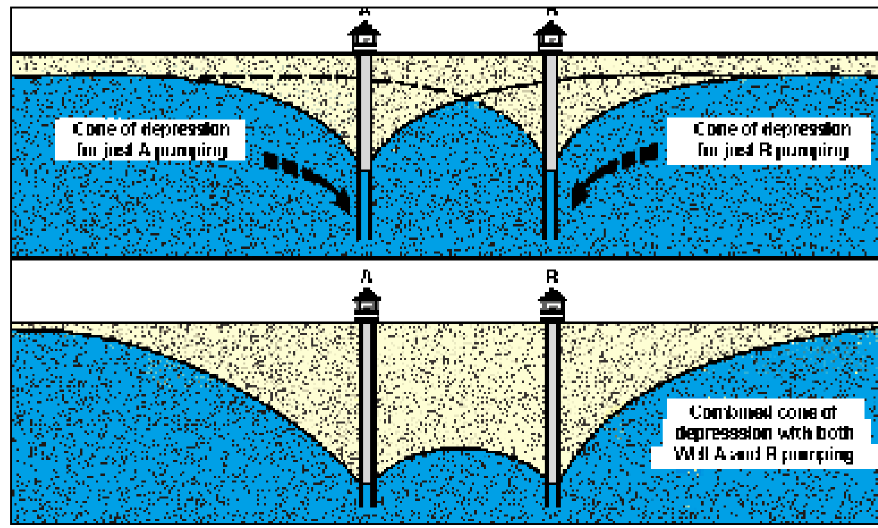
When **groundwater** is pumped out of an aquifer, the pumping creates a depression in the surface of the water table in the shape of an inverted cone (called **cone of depression**).

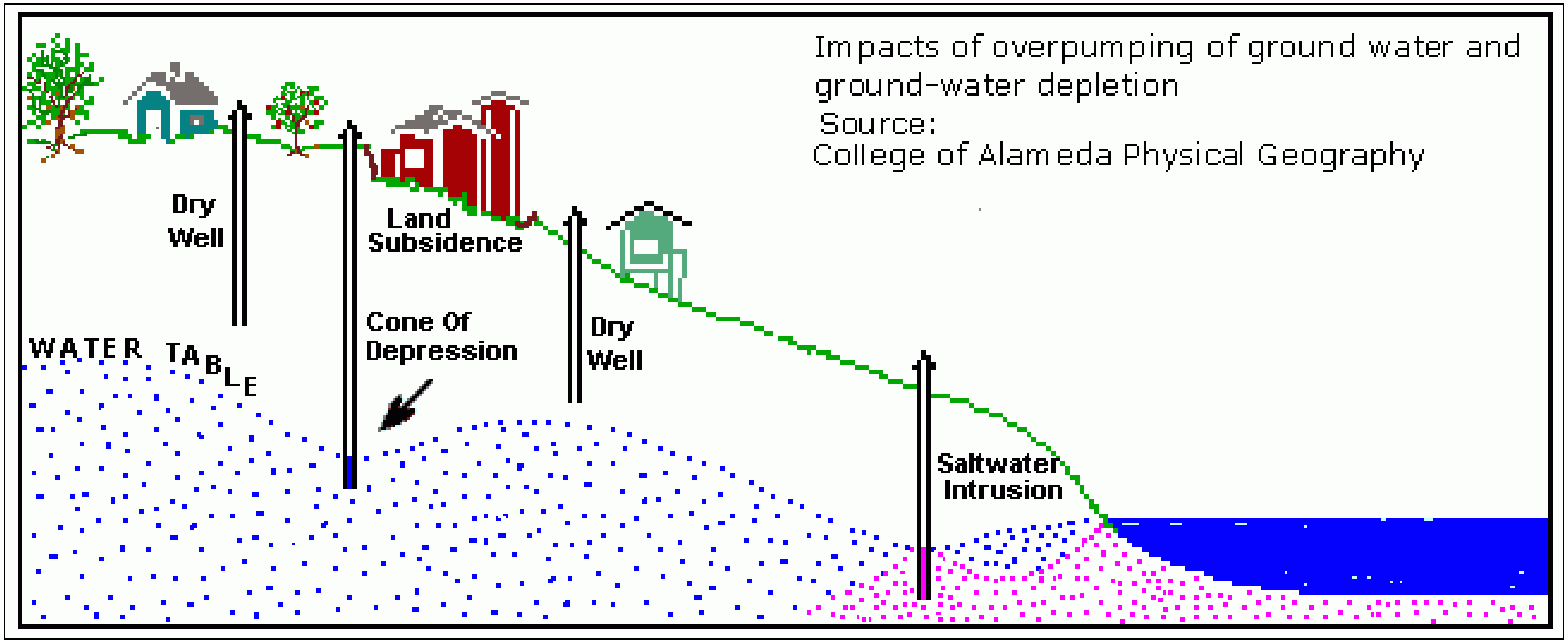
When many pumped wells are close together, these cones of depressions may begin to overlap.

This can cause a regional depression in the level of the water table.

Regional lowering of the water table commonly leads to ground **subsidence** in the area overlying the aquifer.



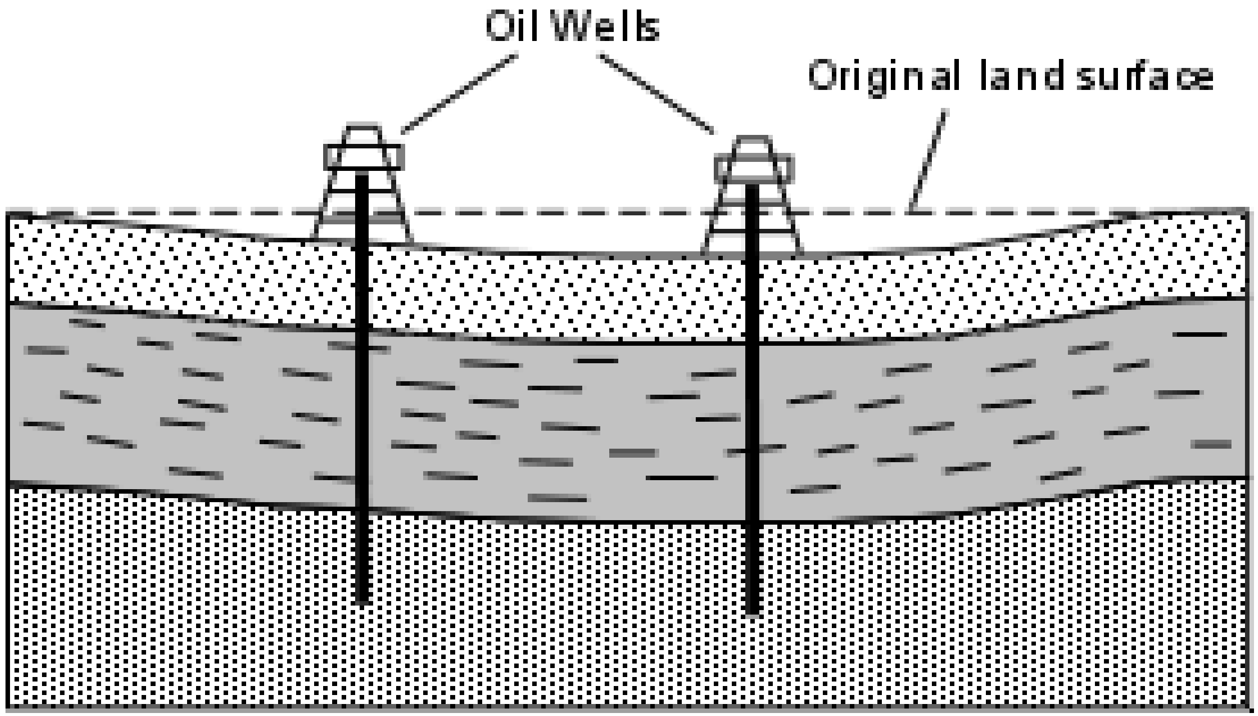



Impacts of overpumping of ground water and ground-water depletion
Source:
College of Alameda Physical Geography
Dry Well
Land Subsidence
Cone Of Depression
Dry Well
WATER TABLE
Saltwater Intrusion

Oil and **Natural gas** are both fluids that can exist in the pore spaces and fractures of rock, just like water.

When oil and natural gas are withdrawn from regions in the Earth near the surface, fluid pressure provided by these fluids is reduced.

With a reduction in fluid pressure, the pore spaces begin to close and the sediment may start to compact resulting in **subsidence** of the surface.



This has occurred recently in the **oil fields** of **southern California**.

For example, in the **Wilmington oil field of Long Beach**, **California**, **subsidence** was first recognized in **1940** due to **withdrawal of oil** from the subsurface. The area affected was about **50 km²**. Near the center of this area, the surface subsided by up to **9 meters**.

In **1958** repressurization of the area was attempted by pumping fluids back into the rocks below. By **1962** further subsidence had been greatly reduced, and the area continuing to subside had been reduced to **8 km²**. Still, up to this point, very little uplift had occurred to restore the area to its original elevation. This subsidence event has cost over **$100 million**.

Sinking Cities

Cities built on **unconsolidated sediments** consisting of clays, silt, peat, and sand are particularly susceptible to **subsidence**.

Such areas are common in **delta areas**, where rivers empty into the oceans, along **floodplains** adjacent to rivers, and in **coastal marsh lands**.

In such settings, **subsidence** is a natural process. Sediments deposited by the rivers and oceans get buried, and the weight of the overlying, newly deposited sediment, compacts the sediment and the material subsides.

Building cities in such areas **aggravates** the problem for several reasons.

- Construction of buildings and streets adds weight to the region and further compacts the sediment.
- Often the areas have to be drained in order to be occupied. This results in lowering of the water table and leads to hydrocompaction.
- Often the groundwater is used as a source of water for both human consumption and industrial use. This also results in lowering the water table and further hydrocompaction.
- Levees and dams are often built to prevent or control flooding. This shuts off the natural supply of new sediment to the area. In a natural setting sedimentation resulting from floods helps replenish the sediment that subsides and thus builds new material over the subsiding sediment, decreasing the overall rate of subsidence. When the sediment supply is cut off, the replenishment does not occur and the rate of subsidence is enhanced.

The table below shows a list of **cities throughout the world that have been experiencing subsidence problems**. Note that most of these cities are **coastal cities** like **London**, **Houston**, and **Venice**, or are **built on river flood plains** and **deltas**, like **New Orleans**, **Baton Rouge**, and the **San Joaquin Valley of central California**.

		Maximum Subsidence (m)	Area Affected (km^2)
Coastal	London	0.30	295
	Venice	0.22	150
	Taipei	1.90	130
	Shanghai	2.63	121
	Houston	2.70	12,100
	San Jose	3.90	800
Inland	New Orleans	2.00	175
	San Joaquin Valley	8.80	13,500
	Baton Rouge	0.30	650

Predicting and Mitigating Subsidence Hazards

The exact place and time of a disaster related to subsidence **CANNOT** usually be **predicted** with any degree of certainty.

This is true of both **slow subsidence related to fluid withdrawal** and **sudden subsidence related to sinkhole formation or mine collapse**.

Mitigation is the best approach to these hazards.

In an ideal world, all areas susceptible to such hazards would be well known and actions would be taken to either **avoid causing the problem if it is human related**, or **avoid inhabitance of such areas if they are prone to natural subsidence**.

For **subsidence caused by sudden collapse of the ground to form sinkholes**, several measures can be taken.

a

Geologists can make maps of areas known to be underlain by rocks like limestone, gypsum, or salt, that are susceptible to dissolution by fluids. Based on knowledge of the areas, whether active dissolution is occurring or has occurred in the recent past, and knowing something about the depth below the surface where these features occur, **hazard maps** can be constructed.

b

Once these areas have been identified, **detailed studies** using drill holes, or ground penetrating radar can be used to locate open cavities beneath the surface. **These areas can then be avoided when time comes for decisions about land use.**

c

In areas where there is a possibility of sudden collapse, **one should be aware of any cracks that form in the ground**, especially if the cracks start to form a circular or elliptical pattern. Such ground cracking may be an indication that a collapse event is imminent.

d

In areas located above known mining operations or former mining operations, **maps can be constructed based on knowledge of the actual locations of open cavities beneath the surface**. Such maps can then be used as a guide for land use planning. Currently laws are in place to prevent active mining beneath urban areas, but these laws did not always exist, and older mines could still cause problems.

Where fluid withdrawal is the main cause of subsidence

a

Information on the rate of fluid withdrawal should be determined and combined with **studies of the material in the subsurface** based on sampling with drill core methods. If subsidence is suspected or observed, **human activities can be modified** to prevent further subsidence. <u>For example</u> **new sources of water can often be found**, or **waste water can be treated and pumped back into the ground** to help maintain the level of the water table, maintain fluid pressure, or re-hydrate hydrocompacting clays and peat.

b

Fluid withdrawal problems are complicated where **laws are in conflict**. **Rights to withdrawal of an underground resource** like water or oil usually take precedence over the **rights to sue for damages that might result from subsidence**.