Land Subsidence, Earth Fissures Change Arizona's Landscape

by Joe Gelt

Mostly underground and out of sight, the effects of groundwater over-pumping and declining water tables are difficult for many people to envision, much less conceptualize. The most apparent and tangible manifestation of excessive groundwater pumping seems to be the political and public policy debates the issue provokes. In other words, the most obvious effect of groundwater overdraft in Arizona is the Groundwater Management Act.

With the increasing occurrence of land subsidence and resultant earth fissures in certain areas of the state, the consequences of dropping water tables become distinct, physical and sometimes dramatically visible. Land subsidence and fissuring provide tangible evidence that the over withdrawal of groundwater has geological as well as public policy consequences.

Arizona, A Land of Subsidence

Subsidence and earth fissures are geological events that are accelerated by man through a long-term extraction of groundwater, and they represent a disruption of a natural equilibrium. Underlying groundwater is pumped and the land settles and subsides. Under certain circumstances fissures then develop.

Using and eventually overusing its groundwater resources have been a way of life in Arizona. Colorful legends of the Old West pale in comparison with this pump-and-consume legacy in explaining Arizona's growth and development and its current level of civilization. Land subsidence and related problems are then consequences that cannot be ignored.

By some measures, Arizona's subsidence problem has been a long time coming, since the beginning of the century. About 1900 the state's groundwater resources began to be exploited, with withdrawals greatly increasing in the late 1940s. The alluvial aquifer system continued to be a major source of water supplies through the boom years, until by 1984 almost 196 million acre-feet had been withdrawn. Groundwater withdrawals were greatly exceeding recharge.

As a result, the water table in various areas of the state dropped significantly, areas that may now be affected by land subsidence. For example, in two southern Arizona areas groundwater levels have dropped more than 500 feet.

One area occurs southwest of Casa Grande near Stanfield, and the other is located south of Chandler near Chandler Heights.

South-central Arizona is the main area of the state affected by subsidence. The geological conditions of the area are such that an over pumping of the underlying stores of water can result in the settling of the land or subsidence. The geological classification of this area of Arizona is basin and range.

This basin and range topography is an extensive swath of territory that extends from west Texas through southern New Mexico and the southwestern half of Arizona and into the Mojave desert. It includes almost all of Nevada, western Utah and up to southern Oregon. Within this area subsidence has been detected at various areas. Along with its occurrence in Arizona, where land-subsidence areas cover more than 3,120 square miles of land, subsidence has affected areas in Las Vegas, Nevada and Demming, New Mexico.

The occurrence of subsidence in south-central Arizona is a major concern because it is a core area of the state, with major agricultural and urban centers. The Phoenix and Tucson metropolitan areas are located within this area, as well as the agricultural production areas within Pinal and Maricopa Counties. This is an arid region of extensive groundwater pumping.

An Arizona Land Subsidence Committee was formed by Governor Babbitt in 1980 to address state concerns. The committee was made up of state and federal agencies including the Arizona Department of Water Resources (DWR), the Arizona Department of Transportation, the United States Geological Survey (USGS), and the Bureau of Reclamation (BuRec). The intent of the committee was to inventory subsidence zones and fissures and to investigate related issues. The committee, which represented the only state-wide effort to address subsidence/fissure problems, was not granted any appropriations.

Causes of Land Subsidence

There is obviously more to subsidence than meets the eye. What is seen at the surface when land settles and subsidence occurs is the end result of a process that begins deep underground, with the occurrence, use, and overuse of groundwater.

South-central Arizona consists of broad alluvial valleys or basins, bordered by mountainous terrain of igneous, metamorphic, and consolidated sedimentary rocks. The basins are broad and low sloping. Underneath are permeable unconsolidated to moderately consolidated alluvium or loosely compacted alluvial sand and gravel. As much as 10,000 feet of alluvium might fill a basin. Here vast volumes of groundwater are stored. The groundwater occurs within the cracks and pore spaces of the alluvial fill.

As water is pumped from an aquifer, the water occupying the spaces between the rock particles is removed and the water level, described as the water table, drops. Without the water, the particles then become more tightly packed together. In other words, the particles compact and consolidate.

With the continued pumping of groundwater without adequate recharge, the sediments become increasingly compressed causing the land to settle or subside. This lowering is called land subsidence and is caused by the compaction of the aquifer. Subsidence occurs gradually and spreads over wide areas.

Different factors determine the occurrence and extent of land subsidence. A basic factor of course is groundwater withdrawal, but other factors also contribute to the situation. For example, when compressed, fine-grained sediment silt and clay compacts more than coarse-grained sediment composed of sand and gravel. Subsidence therefore is more likely to be a problem in areas underlain by clay- bearing layers and where the water table has decreased 100 feet or more.

Groundwater depletion is not the only cause of land subsidence. Subsidence also results from oil and gas withdrawal, the removal of rock during underground mining operations, and the drainage of marshlands. In Arizona however land subsidence is associated chiefly with excessive groundwater withdrawal.

Causes of Earth Fissures

A related phenomenon, earth fissures are the most visible, and sometimes even spectacular manifestation of land subsidence. At one time not associated with the removal of underlying groundwater, fissures were once blamed on other natural geological forces.

Fissures usually are noticed first as land cracks or crevices, a break in the earth's surface. They can then grow considerably by water erosion. Gullies or trenches may be up to 50 feet deep and 10 feet wide, with the fissure extending hundreds of feet below the surface. The fissure may range in length from a few hundred feet to over 8 miles. The average length of a fissure is measured in hundreds of feet.

Fissures develop because of differentiated subsidence or compaction. In other words, fissures result when subsidence is not uniform over an area because of differences in geology and rates of groundwater pumping. As a result, a subsiding land mass may not settle smoothly and evenly like snow falling on a flat surface. Some areas may sink slightly deeper and at a different rate than other areas. Fissures may then result.

How the land settles depends upon characteristics of the underlying basin. The bedrock may include various irregularities such as ridges, hills or fault scarps that are completely covered by alluvial fill of sand, gravel, and clay. The compaction of the alluvial fill over such bedrock features may be uneven and result in fissuring, especially if they are less than 300 meters below the surface.

For example, land settling over areas of shallow bedrock will obviously not settle as deeply as a land mass underlain by thick alluvial fill. Bedrock is found within basins at variable depths. It often occurs close to the mountain ranges and, as a result, fissures commonly form along the margins of a subsiding basin. Here the alluvial soil pulls away from the mountains at the basin's edge because of uneven settling.

Fissuring may result from other conditions as well. A variation in the type and thickness of the alluvium might explain the occurrence of fissuring. These alluvium characteristics may vary within a basin. Also variations in water-level decline can be a factor to explain fissuring.

Fissures begin as tension cracks below the earth's surface. They first become visible above ground as slight, hairline cracks or a line of holes. Flowing water either above or below the surface enlarges the opening, and eventually its surface covering or roof collapses exposing the fissure. The crevice traps surface water drainage and erodes into a deeper and wider gully or trench, until it becomes a prominent feature of the landscape.

The crevices or cracks of the fissures act as a sort of furrow for seeds to settle into and germinate. Vegetation then grows. Sometimes creosote bushes line the edge of a fissure making it especially prominent in aerial photographs where the vegetation shows as a dark outline of the fissure.

Once fissuring begins in an area the process tends to continue, increasing in number and length, with fissures forming adjacent and parallel to older fissures. Fissures spread at uneven speeds and in uncertain directions growing or branching out, sometimes forming complex patterns of multiple fissuring extending for miles.

Fissures are not to be confused with arroyos or washes, legendary land crevices of western regions. Arroyos are formed by surface runoff and provide natural drainage. Fissures result from land subsidence and often cut across normal drainage patterns, often running perpendicular to them. Surface flow in fissures may move laterally, but also sinks downward, possibly into the groundwater table. Also, unlike arroyos, earth fissures extend deep in the ground.

Subsidence and Fissure Locations in Arizona

Subsidence and fissures were at one time perceived to be strictly agricultural problems, the consequences of an areas' extensive use of groundwater. For example, subsidence has affected over hundreds of square miles in the Arizona agricultural areas of Eloy, Picacho, Maricopa, and Stanfield.

Urban centers meanwhile grew and expanded and, as a result, also began to experience land subsidence problems. This was not just because cities were pumping great stores of groundwater. As urban areas expanded, they sometimes reached into former agricultural areas, lands possibly already prone to subsidence and fissuring.

This type of development is still occurring. New developments continue to be built in outlying areas, often with a water-consuming golf course as a central feature. Cities may thus be ensuring a future land subsidence problem. Some officials believe subsidence will become an increasingly serious problem in urban areas, unless groundwater pumping is more carefully controlled.

Subsidence was first detected in Arizona in 1948 near Eloy in the lower Santa Cruz basin. Follow-up studies found that subsidence was an ongoing phenomenon in the Eloy area. About 675 square miles of the area were determined to be affected by subsidence by 1977. Subsidence of about 12.5 feet had occurred in the Eloy area by this date, with more than 15 feet of subsidence evident by 1985. The Eloy area is the center of subsidence activity in the state.

Stanfield, which is located about 30 miles northwest of Eloy, was also identified as a major subsidence site. By 1977 about 425 square miles in the Stanfield area were affected by subsidence. Subsidence in the area measured 11.8 feet at this time.

Within the Salt River Valley are various locations where subsidence is occurring. In the Queen Creek-Apache Junction area about 230 square miles had subsided more than three feet by 1977. Near Luke Air Force Base west of Phoenix and in the western part of the Salt River Valley 140 square miles also had subsided more than three feet by 1977. At an area east of Mesa 5.2 feet of subsidence was measured. Subsidence has also been recorded in the Paradise Valley area in eastern Salt River Valley where land has subsided as much as five feet between 1965 and 1982.

Other Arizona areas affected by subsidence include: northwestern Avra Valley near Red Rock; Harquahala Plains; areas northwest and southeast of Willcox; Bowie and San Simon areas; a location near Tonopah in the lower-Hassayampa area; and the Gila Bend basin.

Subsidence in the Upper Santa Cruz basin is of special concern because it is an area of extensive groundwater pumping to support municipal, agricultural and industrial activities. It is also the location of a major Arizona metropolitan area, Tucson.

Where subsidence occurs, fissures are a possible occurrence. Not a wide-ranging phenomenon, fissures are known to occur in only six U.S. states. And among these states, Arizona has the dubious distinction of having the greatest number of earth fissures caused by groundwater withdrawal. Some authorities even claim Arizona ranks first in the world in this regard.

Arizona's first recorded fissure was observed in 1927 near Picacho. Since that time, with increased pumping of groundwater, fissuring has intensified in several south-central basins in Arizona. Another landmark in the history of Arizona fissures occurred in 1980 when a 429-foot fissure opened in a northeast Phoenix construction site. This was the first to occur in a nonagricultural, densely populated area and the first in the Phoenix area.

Since the 1950s the occurrence of fissures has greatly increased, with hundreds now identified in the alluvial basins of southern Maricopa, western Pinal, western Pima, and northwestern Cochise Counties. Most fissures however are found in Pinal and Maricopa counties.

In Arizona, and indeed in the world, the lower Santa Cruz basin is the site of the greatest concentration of earth fissures. This is an area where a sizable groundwater level drop was measured and significant subsidence recorded. Fissures occur in the desert by the west side of the Picacho Mountains, the east side of the Casa Grande Mountains, and south of the Sacaton Mountains. Fissures have formed west of Stanfield, and along the southwest side of the Santa Cruz Flats. Fissures are also located near Marana, 25 miles north of Tucson.

Studies indicate that no fissures existed along the Casa Grande Mountains, southeast of Casa Grande in 1949. In 1951 the existence of a single fissure was demonstrated. By 1980 there were 50 fissures, with some in areas formerly cultivated. This area also has the distinction of having the longest fissure zone in Arizona. An unusually extensive, ten-mile long fissure system is located in the lower Santa Cruz basin, east of the town of Picacho in Pinal County.

Earth fissures have been identified also in other areas where groundwater depletion is of concern, including Harquahala Plains; McMullen, Salt River, and Avra Valleys; and the Willcox and San Simon basins.

Problems Caused by Subsidence and Fissures

Subsidence and land fissures, which are slow and gradual developments, do not pose the type of hazards associated with sudden and catastrophic natural events like floods and earthquakes. Looking across an expanse of subsiding land, a viewer may not perceive any evidence of the settling land mass. The most pronounced effect might be increased erosion near mountains.

Place man-made structures and projects on that expanse of land-- works designed for specific elevations and gradients--and subsidence is likely to take a toll. Damages that result from subsidence and fissures often are costly and disruptive.

For example, subsidence can be costly to farmers in a number of ways. Irrigation ditches and canals might be broken as land settles. Uneven and irregular subsidence could alter the slope of previously leveled fields, disrupting the flow of irrigation water. Fields may then have to be releveled, as had to be done in the western Salt River Valley, the lower Santa Cruz basin, and the Willcox basin.

A developing fissure cutting across an irrigated field may cause sections of land to be taken out of production and abandoned. The crevice remains as a hazard to people, livestock and wildlife.

The effect of subsidence on well casings can be curious as well as destructive. As land subsides, casings from deep wells may seem to rise into the air, as if they were growing from the ground. The casing is not rising, of course, but the earth is sinking. Well cases may also collapse under the pressure of subsidence necessitating expensive repairs and even the replacement of wells. Large irrigation wells can cost from $100,000 to $200,000.

Land surveyors experience difficulties because of subsidence. They may have difficulty closing traverses in certain areas of the state. Bench marks in subsidence areas may have settled while those on bedrock may not have. Surveying data quickly become obsolete. Expensive releveling may be needed.

Urban areas are especially vulnerable to the effects of subsidence. Cities are dense of population, with clusters of buildings and facilities. Also within urban areas are the varied projects and structures--bridges, highways, electric power lines, underground pipes, etc.--that make up the urban infrastructure. There is therefore much to damage in the movement of a land mass, even the gradual settlement of subsidence.

For example, subsidence may necessitate repairs to streets and highways and could result in the rupture of water mains, sewer lines and gas pipes. Building foundations might crack. More frequent and costly maintenance may be required. Those structures that cover large areas or have height are especially vulnerable. Any system that depends on gravity flow could be disrupted if differentiated subsidence shifts the gradient. For example, a change in the gradient of a sewer line or storm drain could interrupt flow causing it to reverse or clog. Such an event occurred in northeast Phoenix where the gradient of sewer lines decreased due to subsidence. Also subsidence might cause gravity flow aqueducts to overflow. Costly new designs may have to be worked out for such systems to accommodate the threat of subsidence.

Railroads, earthen dams, wastewater-treatment facilities and canals also are vulnerable to damage from subsidence. Any structure built across the path of a fissure likely will suffer serious damage.

Groundwater pollution also is concern. Earth fissures may be quite deep, possibly extending to the water table. Surface flow and its possible contaminants--chemicals, animal waste, etc.--may therefore have a direct channel to the water table, without percolating through the unsaturated zone for filtration. That fissures often are used as convenient sites to dump trash and refuse compounds the potential threat to groundwater quality.

Finally, it is worth emphasizing that land subsidence and the damage and destruction they cause should not be interpreted merely by their effects on humans, their activities and structures.

Even if land subsidence were to occur in the remoteness of the desert, unnoticed and posing no threat to humans, it still is an ominous occurrence. Once again humans have seriously disrupted a natural process and caused severe environmental damage. This is the most formidable consequence of land subsidence.

Subsidence and fissures are therefore forces to be reckoned with. Now nearing completion, the CAP project was designed, constructed and is being maintained to prevent damage from subsidence and fissures. Meanwhile, as mentioned, subsidence is a relatively new phenomenon to some Arizona cities. For example, the extent of its occurrence in Tucson is currently being studied, with its possible effects interpreted.

Subsidence, Fissures and the CAP Canal

CAP offers a case study of coping with subsidence and fissures. Never before in Arizona has such a complex manmade project reached across such an extensive area of the state, 335 miles from Lake Havasu to Tucson. This territory includes areas of groundwater overdraft, areas susceptible to subsidence and fissures. The project consists of concrete-lined canals, siphons, tunnels, pumping plants, and pipelines.

The U.S. Bureau of Reclamation (BuRec) identified various possible causes of disruption to the CAP system. Along with floods and fire, earth fissures and subsidence were events to be carefully considered when designing, constructing, and operating the CAP.

BuRec and the U.S. Geologic Survey began geologic studies in 1977 to determine the hydrogeologic conditions associated with land subsidence and earth fissuring. The studies were to determine the expected subsidence that CAP design would need to accommodate and to identify areas of fissure hazards.

Also, work was to be done to devise ways to monitor future land subsidence along the CAP route. The investigations included field reconnaissance and mapping, test drilling, borehole instrumentation, and geophysical surveys. Subsidence predictions were worked out for the aqueduct route for the 50-year period ending in the year 2035, and range from four inches to over 15 feet on the Salt-Gila Aqueduct and from about two feet to almost eight feet on the Tucson Aqueduct.

With subsidence predicted and expected, engineering design techniques were needed to mitigate any resulting adverse effects. Such techniques included additional canal freeboard, reinforced concrete lining, overbuilt overchutes, trapezoidal road crossings, and modified check structures. Each represents a method to protect CAP operations from serious disruption because of subsidence.

For example, additional canal freeboard is constructed in areas of subsidence concern. This means that in such areas the canal is built with a margin of ten feet from the surface of the water to the top of the canal lining. If the canal settles, the banks are protected and the flow is maintained.

Because of the potential of fissures to cause serious disruptions to CAP flow, project operations also include careful monitoring and emergency mitigation of fissures. Early detection and treatment of fissures are essential to ensure the safety and continued operation of the CAP aqueduct system.

Early surface traces of fissures and subsurface irregularities are carefully mapped, with regular monitoring to determine fissure growth and direction, especially if toward CAP structures. Studies have identified existing fissures located within about two miles of the canal alignment, and potential fissure hazard zones are defined.

With fissure zones identified, a strategy of avoidance can be implemented. The CAP route was planned to bypass known areas of subsidence and fissures. For example, east of the town of Picacho a ten-mile long fissure zone exists. To avoid this zone the canal was routed along the base of the Picacho Mountains, northwest of Picacho Peak.

Despite its rerouting, the canal unavoidably traverses some fissure hazard areas. One area is in Avra Valley, about 35 miles northwest of Tucson. Another area of concern is in Apache Junction in the Phoenix metropolitan area. The Eloy Basin is another area where subsidence and fissuring have threatened the CAP aqueduct.

Thus far nine fissures have necessitated corrective measures on the CAP system. The strategies in place to cope with threatening fissures include filling in and bridging the fissure with gravel. This method however has proven to be of limited success. The most effective method has combined sealing the fissure with rerouting drainage away from it. Surface flows therefore can not enter the fissure, and it is unlikely to erode into a large destructive gully.

In areas threatened by fissures the canal lining has been reinforced with steel. If a fissure occurs, the canal lining supports itself until repairs are made. This design was tested in the Cortaro area when a large fissure opened up beneath the canal. Repairs were able to be made without the canal collapsing.

To date the main CAP canal has not suffered any serious consequences from fissuring and subsidence. This is mainly because sufficient funding and trained personnel have been available to cope with any developing and threatening situation. These advantages are not usually available to operators of offshoot or lateral canals. As a result, the more serious fissuring problems have occurred in canals leading from the main aqueduct. Such problems have developed along the Santa Rosa canal and Maricopa-Stanfield Water District canals.

Tucson and Subsidence

A recent study indicated that the subsidence rate in parts of the Tucson basin is increasing. If this, in fact, is occurring, then the event might presage a development expected by some geologists; i.e., subsidence as a growing problem in urban areas in Arizona.

Subsidence has been detected in certain urban areas of the state. It has occurred for example in sections of the Phoenix metropolitan area. And even some of the subsidence in the Casa Grande area may be attributable to urban groundwater use. That subsidence is occurring in Tucson has been recognized for a period of time. The concern now is that the Tucson subsidence rate is increasing. The damage and disruption to be expected from extensive subsidence occurring in a large metropolitan area thus gain importance as an issue.

Research has demonstrated that between 1947 and 1981, the Tucson basin ground surface dropped 3 millimeters (twelve-hundreds of an inch) for every meter of water loss. Recent research conducted by John S. Sumner, University of Arizona professor emeritus of geosciences, and graduate student Michael A. Hatch indicates that between 1987 and 1991 the surface of the Tucson Basin dropped an average of 24 millimeters (about an inch) for every drop of one meter in the water table, with subsidence ranging from half an inch to 2 inches. The water table under Tucson has been dropping about one meter or over three feet a year since the 1940s.

Hatch points out that if the average subsidence rate in the Tucson basin of a half-inch to two inches per year continues for the next 30 years, much of the basin will settle about a foot during that time. Some areas might even subside up to four feet.

Sumner and Hatch further suggest that the subsidence rate may be increasing because of a loss of elasticity within the basin, the result of various subsurface developments. Because of the consistent groundwater pumping within the area, the water table might have dropped below the clay layers. Without the water, the clay particles are compressed more tightly by the weight of the overlying rocks, and their water storage capacity is thus permanently reduced. Subsidence would then be inelastic because the sinking of the ground surface is permanent. Recharge would not reverse the process.

It is generally agreed that more research is needed to confirm the above findings. Meanwhile geologists speculate about various possible consequences of subsidence occurring in the Tucson Basin. Some believe that if subsidence is general and uniform throughout the area, disruptions will be very minimal. Others believe that inelastic subsidence in fact is occurring and eventually will result in fissures developing in areas of Tucson.

Predicting, Identifying and Monitoring Subsidence, Fissuring

Subsidence and earth fissures are problems not easily halted. Efforts are needed therefore to predict their occurrence as well as monitor their development to ensure that people and their projects remain out of harm's way. Much pioneering work in this area is being done in Arizona.

Predicting and interpreting areas of subsidence were essential when planning the CAP route. This was done by using test wells and geophysical surveys to establish soil profiles to measure the settlement of subsurface soils within an area. This determines the extent to which the soils are dewatered and therefore susceptible to compaction. Well records of the areas also were examined to ascertain a history of pumpage. Also, the history of subsidence in the area was researched by reviewing benchmark placements. The future occurrence of subsidence then was estimated through analysis.

The Global Positioning System is another method to monitor subsidence. GPS uses satellites to fix the latitude, longitude and elevation of a point. Results are compared with previous readings to determine the rate of land subsidence. GPS enables quick and accurate positioning to within a fraction of an inch. The method is relatively recent however. As a result, sometimes long-term survey records do not exist to compare with recent GPS readings.

UA geoscientist John S. Sumner is using GPS to monitor subsidence within the Tucson Basin. CAP officials look to eventually using GPS to monitor subsidence along the entire canal route. Meanwhile, traditional surveying methods are presently converted to GPS.

Although readily apparent when open at the surface, fissures are difficult to predict and identify at an early stage in their development. Horizontal extensometers are tools for accomplishing this complex task. An extensometer is essentially a micrometer hooked to two wires, each attached to a stationary post. The stretching and contracting of the wires is measured to interpret tensions.

Vertical extensometers are placed beneath the ground in the bottom of wells in areas with geological conditions favorable to the formation of fissures. In such areas soils may be settling into bedrock, and the process produces tension. Extensometers measure the tension in the soil to interpret the probability and development of fissures. The devices are installed at 24 sites in southern Arizona including sites in Tucson, Casa Grande, the Eloy area, Avra Valley and Pinal County.

Aerial photography is a basic and fairly reliable method to identify new fissures and monitor existing ones. This strategy was the focus of a joint effort between the BuRec and the Arizona Geological Survey. Photographs were taken periodically of certain areas and compared with earlier images to determine fissure growth. Although useful, this method is limited because complete photographic records of certain fissure areas are not available.

Other methods are more experimental. Charles E. Glass, UA associate professor of mining and engineering, is working on physical models to predict subsidence and fissures. The work is still at the research stage. Michael Pegnam assisted by Aaron Glass--both are students of Glass--modeled three Arizona basins, with fairly accurate results. Glass hopes eventually to develop a model of the Tucson basin.

USGS geologists also believe that acoustic emission surveys are a promising method for predicting fissures along the CAP canal, although no work has been done thus far with the method. As tension or tensile stress builds up in the ground, micronoise or acoustic signatures are emitted. Listening posts could be installed about every ten feet along the canal to provide data points for monitoring or listening to the emissions. The growth of a fissure could then be tracked.

Conclusion

An important water issue in Arizona is the use and overuse of groundwater. The implicit, sometimes explicit message of the groundwater laws, regulations and conservation campaigns is that we need to take care of our groundwater resources to ensure the continued growth and development of the state. Much less is heard about managing groundwater to avoid land subsidence and earth fissures.

In fact, the groundwater issue is discussed in terms that suggest that the threatened consequences of groundwater overuse is temporary and redeemable. Groundwater is described as overdrawn calling to mind a checking account that could be put to right with additional cash deposits. And groundwater recharge can replenish depleting aquifers. Safe yield is achievable when an equilibrium is reached between recharge and withdrawal. What is suggested is that the groundwater situation is a temporary condition that can be fixed. And in some cases this might be true.

Yet the fact remains that relatively large portions of the state have subsided due to excessive groundwater pumping. And with subsidence often comes fissuring. Fissures slice across lands causing environmental damage and threatening structures and disrupting human activities. These are assuredly not temporary effects. Fissures pose threats to both agricultural and urban areas.

The implementation of the Groundwater Management Act and the completion of the CAP project are to relieve the state of its reliance on groundwater reserves. These endeavors should indeed help reduce the occurrence of subsidence and fissures, but their beneficial effects are limited to certain areas of the state and, further, will take time to work out. Meanwhile subsidence and fissures continue to be a concern.

Many scientists and officials stress the need for more research to be done to better understand the occurrence of subsidence and fissuring. This then will lead to better tracking of such occurrences, from predicting and early identification to monitoring and remedial actions.

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The ideas and opinions expressed in the newsletter do not necessarily reflect the views of any of the above people.
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