HAZARDOUS CRACKS RUNNING THROUGH ARIZONA

People — and their groundwater usage habits — are the source of a hazard in the western United States, in which small cracks in the ground grow to enormous depths, collapsing the earth.

Ray Harris and M. Lee Allison

One warm morning last August, Pam Devries opened the front door to the four-bedroom home she and her husband bought a year earlier in rural Chandler Heights, southeast of Phoenix, Ariz., and found a surprise. Although the heavy rain the night before was a welcome relief from high temperatures and drought-stricken vegetation, it left something unwanted in its wake: a gully five meters deep and three meters wide that had swallowed a good part of Devries' yard and now extended the length of her neighborhood. As she stared, horrified, at her yard's new feature, water runoff still poured into the seeming abyss. That morning was Devries' first exposure to the little-known geologic hazard of earth fissures — large cracks caused from groundwater depletion.

Devries was not alone in her experience. The same rain produced flooding that affected broad areas of unincorporated Chandler Heights. Some of the runoff found its way into an old fissure system, parts of which had been covered over for development. As water flowed through the fissure and under the capping of dirt, the surface collapsed into the underlying void, and the old fissure was reborn — and the yards of Devries and her neighbors disappeared in a meters-deep chasm.

That particular fissure was first reported in 1962, having formed a few years earlier. Residents who had recently moved into the area and were unaware of earth fissures were quite shocked and angry. A storm of public outrage ensued.

The fissures were not news, however, to geologists. For more than 40 years, geologists have warned people about the hazards of earth fissures in Arizona, but until recently the warnings often went unheeded. In the past, earth fissures were considered an interesting phenomenon, but because they occurred mostly in undeveloped areas where few people lived, they were not perceived as a problem. But with the population expanding in recent years into areas known to have fissures, the potential for damage to property has increased, particularly with old fissures being filled in, concealing the potential risk.

New residents may be completely unaware that earth fissures lurk below their yards or under their homes, but with new mapping efforts and education, short-term solutions are possible. The issue today is less a problem of earth fissures forming where people have built houses than it is of people building houses on or near fissures without knowing it. Making people aware of the issue is the first step. In the long run, however, people may need to change their groundwater usage habits to curb the problem.

SINKING LAND

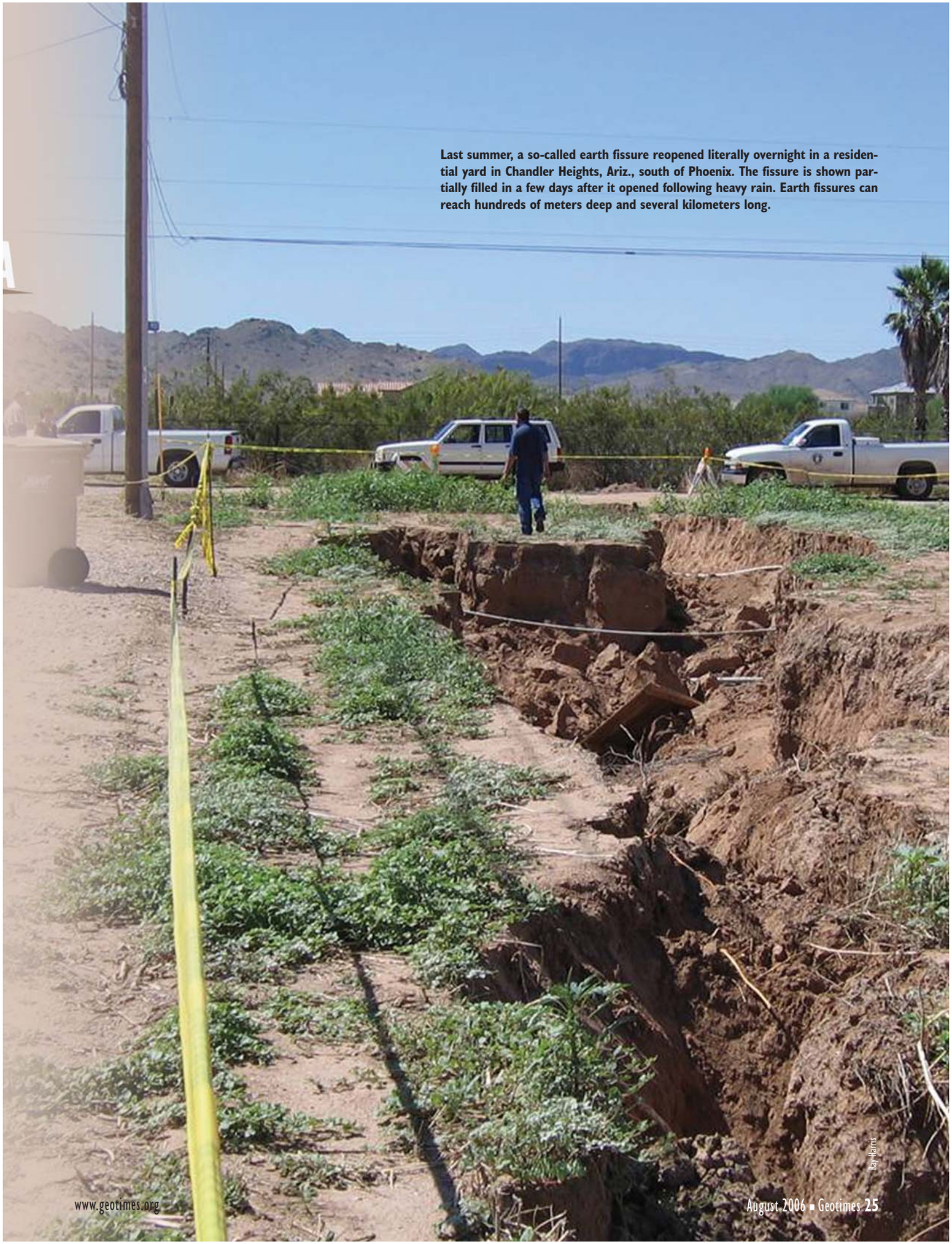
Earth fissures occur not only in Arizona, but also in other basins where the groundwater table has dropped precipitously due to overpumping. Fissures are a serious problem in the Las Vegas area, occur in southern Utah and western Texas, and have been recently reported in the small province of Aguascalientes in central Mexico where as many as 200 homes and a hospital are reported damaged.

An earth fissure at the surface results from large quantities of soil or sediment being washed down into a crack that may initially be only a few centimeters wide, but a hundred meters or more deep and a kilometer or more in length. The longest fissure zone mapped in Arizona has a length of more than 11 kilometers. The condition that leads to the fissures is sinking land.

In parts of Arizona, that condition is prevalent. A large portion of the state lies within the Basin and Range province, which contains deep alluvium-filled basins separated by long narrow mountain ranges. Bedrock is often 3,000 meters or more below the surface. These deep basins hold large quantities of groundwater in storage, but people are pumping more groundwater than nature can replenish.

Where agriculture or municipalities rely extensively or completely on groundwater, the groundwater tables have declined. In the 1940s, large-scale groundwater pumping for agriculture was widespread in the deep basins of Arizona. By the 1980s, groundwater levels in several basins had declined 150 meters or more.

As groundwater tables lower, aquifer sediments lose some of the buoyant support of the water and undergo compaction. If compaction is great enough, the ground surface sinks. By 1992, in the Luke basin immediately west of Phoenix, the land had



Last summer, a so-called earth fissure reopened literally overnight in a residential yard in Chandler Heights, Ariz., south of Phoenix. The fissure is shown partially filled in a few days after it opened following heavy rain. Earth fissures can reach hundreds of meters deep and several kilometers long.

Ray Harris

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subsided about 5.5 meters. In the Picacho basin, about halfway between Phoenix and Tucson, subsidence was more than 4.5 meters by the early 1980s.

Compaction and land subsidence are, to a large degree, irreversible processes. Once the sediments have compacted, the capacity of the aquifer to store water is permanently diminished. Even if the water table rises, the land surface does not rebound significantly. And in most Arizona basins where the land has subsided more than a meter or two, earth fissures have developed.

On the most basic level, earth fissures are tension cracks. Geologists have proposed several ways in which enough strain can be created to cause tensile failure. One mechanism involves one part of the basin subsiding more than another over a short distance. Another mechanism proposes that the viscous drag of groundwater moving through an aquifer pulls the sediments with the water. The drying out of clay-rich sediments may also affect the development of earth fissures (see sidebar below).

GROWING HAZARD

Although earth fissures seem to appear "overnight" following intense rainfall, the precursor fissure may have been forming for years or even decades at depth. In the earliest stages of development, a fissure may first appear at the surface as a series of small depressions or hairline cracks only a few millimeters wide and tens of meters long. Water entering a fissure system may induce fracturing for a great distance from the point of entry. Heavy rain softens the surface material, allowing it to cave into the underlying fissure. Water running into the fissure erodes the sides and washes the material deep down into the fissure system, enlarging the original small crack into an impressive chasm.

Even before they are fully developed, earth fissures can cause significant damage to infrastructure such as roads, canals, railroads and pipelines. Buildings can suffer extensive cracking. Houses have been completely destroyed by fissures that opened up beneath them. The presence of cracks in foundations and walls, however, does not necessarily indicate that subsidence or earth fissures are to blame. Expansive soil, hydrocompaction and normal settling of fill material can also produce cracks in structures.

Fissures also pose a serious threat to water quality because they may serve as open conduits to the water table. Contaminants that enter a fissure may travel almost unimpeded into regional aquifers that supply drinking water. Erosion-enhanced fissures have commonly been used as illegal dumping sites for household garbage, tires, construction debris, and animal waste.

REDUCING THE RISK

The Arizona Geological Survey (AZGS) is the lead agency in the state for earth fissure mapping. Since the late 1980s, the survey has been mapping the hazard, using aerial photos and walking out the alignments in the field. Fissures tend to collect water, so the resulting thicker vegetation stands out well in the photos. But because other factors can also create vegetative or drainage alignments, it is also necessary to physically inspect suspect fissures for verification. Decreased funding over the past decade, however, has hampered efforts to keep fissure mapping current.

Additionally, Arizona laws have not been conducive to reducing the risk. Until recently, land owners, developers and real estate agents were not required to disclose the presence of earth fissures on property being sold. Also, land subdivided into five or fewer parcels was exempted from state requirements for the seller or developer to conduct background geotechnical assessments. With the recent increased awareness of the problem, however, Arizona has begun responding to the growing risk from earth fissure hazards.

Although the most effective mitigation for earth fissures and giant desiccation cracks is to avoid development where they

ANOTHER TYPE OF CRACK

In addition to the classic earth fissure from groundwater pumping (see main story), another type of large crack is becoming increasingly common in Arizona: "giant desiccation cracks," which form when thick layers of clay-rich sediments dry out.

Clay minerals in the sediments tend to swell when wet and shrink upon drying. Shrinkage produces tension that under the right circumstances can build to the point where ruptures form. This process is similar to the ordinary development of mudcracks in a drying mud puddle, but on a much greater scale. The cracks tend to form polygons, which can be 50 to 300 meters across. Giant desiccation cracks are common in southwestern U.S. playas and are widespread in the desert areas of Arizona.

This sinkhole formed last year at the intersection of three giant "desiccation cracks" in southeastern Arizona. Such cracks are the result of dried out clay sediments.

Desiccation cracks are distinguished from earth fissures caused by groundwater pumping by their pattern of complex branching. Individual cracks may be hundreds of meters long and, in some places, are large enough to mimic earth fissures. Earth fissures tend to be longer, straighter and much deeper. Fissures formed by groundwater depletion can branch or have parallel segments, but do not form networks of polygons.

Desiccation cracks typically form at depth and work their way to the surface. Evidence for the initial formation of the desiccation cracks at depth is abundant in the field. It is common to find sinkholes connected by tunnels at depth, with no crack or depression at the surface between them. Such bridging is evidence that the surface has not pulled apart.

In the southeastern part of Arizona, earth fissures and giant desiccation cracks commonly occur together. Desiccation cracks, which are obvious in mid-1930s photos, are older than the Arizona earth fissures, which began to form in the 1960s as a result of groundwater pumping begun decades earlier. Earth fissures may trend into an area of polygonal desiccation cracks and in many cases it is impossible to tell where the fissure ends and the desiccation cracks begin.

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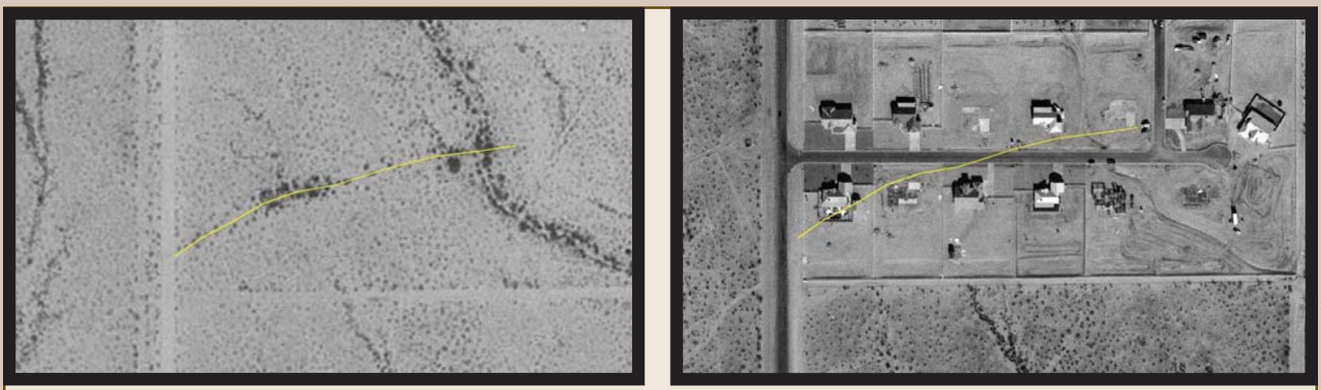

Courtesy of AZGS

An aerial photo of an area northeast of Casa Grande, Ariz., shows the rural, undeveloped character of the area in 1997 (left). The dark patch of vegetation in the center is the result of increased water flow into and along an earth fissure, marked with a yellow line. In 2004, a new housing development was built directly over the earth fissure (right). Land owners were not required to disclose the presence of fissures to buyers until a law went into effect this summer.

are present, it is first necessary to determine their locations precisely. Unfortunately, many maps that show the locations of earth fissures are decades old.

Most of those maps were made before GPS was available, are not digital, and were completed at scales of 1:24,000 or smaller, which are not adequate for the detailed planning needed by developers and local building officials. A sizable number of known earth fissures have never been mapped at more than a regional scale. Some of the existing maps are best termed as reconnaissance-level. In addition, continued groundwater pumping has produced new fissures or extended existing ones in some areas since the last mapping was done.

Legislation just passed in Arizona in June and signed by the governor into law July 1 will fund a fissure mapping program at AZGS. This funding will enable the survey to map in detail all fissures in the state at scales that will allow the public to accurately judge whether their properties are at risk.

New mapping efforts use high-precision GPS instruments to dramatically improve location accuracy over older, hand-drafted maps. Detailed mapping with GPS provides effective monitoring: When an area is revisited, scientists can quickly assess how much a fissure has grown since the last visit.

In addition to providing funding for detailed field mapping, the expanded fissure mapping program will provide funding to enable public access to on-demand, digital maps via the Arizona State Land Department's Web site. This new Web service will allow users to superimpose fissure maps over other GIS layers of their choice so individual properties can be easily identified and assessed.

Additionally, another new state law passed last spring now requires the seller to disclose whether fissures are known to exist on or near a parcel of land. Even with that, however, AZGS continues to hear isolated reports of landowners bulldozing over fissures or dumping layers of rock and soil over them, just prior to developing or putting the land up for sale.

To aid in the communication of the hazard, AZGS is developing training sessions targeted to real estate professionals, homebuilders and local officials, to give each of them critical information to make informed decisions. The seminars include describing the nature, origin, occurrence and impacts of fissures, showing how to find and understand the fissure maps, and discussing what can be done to reduce risk.

AZGS also has resurrected the Center for Land Subsidence and Earth Fissure Information, which includes expanding its Web site (www.azgs.az.gov/CLASEFI.htm) to serve as an information portal about fissures, desiccation cracks, and related geologic hazards in Arizona. The survey is also working with the Arizona Association of Counties to develop a cooperative program modeled after those other states, in which the survey will review hazards reports submitted to the counties by developers, as counties often have little or no expertise to evaluate such reports and no funds to contract for external reviews. The reports will be added to a public state-wide hazards inventory library to better and more easily assess geologic hazards and risks on nearby lands.

HUMAN-MADE SOLUTIONS

Earth fissures occur in response to massive dropping of groundwater tables — events that are rare or nonexistent in nature, and as such, are primarily human-made hazards. The solution is obvious: stop overpumping the groundwater resource. But the combination of rapid population growth in many of the affected basins and an ongoing drought makes that solution often difficult to implement. It also does not solve the problem of existing fissures.

In the near term, solutions will focus on identification and avoidance of fissures, education, and providing technical assistance. Longer term solutions should be oriented towards moderating groundwater overdrafts to prevent fissures from occurring in the first place, predicting areas susceptible to them, and developing effective mitigation techniques.

In some ways, Pam Devries and her neighbors were lucky. They filled in the fissures in their yards and are going on with their lives. Others may not be as fortunate, if fissures open up suddenly directly under homes, businesses or roads.

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